7 THE BODY CAN PROTECT ITSELF FROM INFECTION

UNIT 3 CONTENT

SCIENCE INQUIRY SKILLS

- identify, research and construct questions for investigation; propose hypotheses; and predict possible outcomes
- design investigations, including the procedure(s) to be followed, the materials required, and the type and amount of primary and/or secondary data to be collected; conduct risk assessments; and consider research ethics, including animal ethics
- conduct investigations, including the collection of data related to homeostasis and the use of models of disease transmission, safely, competently and methodically for the collection of valid and reliable data
- represent data in meaningful and useful ways, including the use of mean, median, range and probability; organise and analyse data to identify trends, patterns and relationships; discuss the ways in which measurement error, instrumental accuracy, the nature of the procedure and the sample size may influence uncertainty and limitations in data; and select, synthesise and use evidence to make and justify conclusions
- communicate to specific audiences, and for specific purposes, using appropriate language, nomenclature, genres and modes, including scientific reports

SCIENCE AS A HUMAN ENDEAVOUR

- the decision to participate in immunisation programs can be influenced by the social, economic and cultural context in which it is considered

SCIENCE UNDERSTANDING

Response to infection

- infectious diseases caused by invasion of pathogens in the form of viruses and bacteria can be transmitted from one host to another
- transmission of pathogens occurs by various mechanisms, including through:
  - direct and indirect contact
  - transfer of body fluids
  - disease-specific vectors
  - contaminated food and water
- the body's external defence mechanisms against pathogens include features of the:
  - skin
  - digestive tract
  - urogenital tract
  - respiratory system
  - the ear
  - the eye
- pathogens that enter the body are targeted by non-specific immune responses of inflammation and fever
- immunity is gained through the exposure to specific antigens by the production of antibodies by B lymphocytes and the provision of cell-mediated immunity by T lymphocytes; in both cases memory cells are produced
- passive immunity can be acquired as antibodies gained through the placenta, or antibody serum injections; active immunity can be acquired through natural exposure to the pathogen, or the use of vaccines
- antiviral and antibiotic drugs are used for treating infections and differ in their specificity to pathogens

Source: School Curriculum and Standards Authority, Government of Western Australia

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The human body has a number of mechanisms to protect it from invading organisms. If the body's defences are overcome, the invaders may cause disease. Such disease-causing organisms are called **pathogens**. Some diseases are spread from one person to another. These diseases are **communicable**, or **infectious**, **diseases** and are also called transmissible diseases.

We are often exposed to pathogens without realising it. Luckily, our bodies have a number of defences that protect us from them. Many pathogens are prevented from entering the body or, if they do enter, are dealt with before they can cause symptoms of disease. Even if we do become ill, the body's defence system often enables recovery without any medical intervention.

7.1 PATHOGENS

The most common pathogens that affect the human body are bacteria and viruses, although fungi and animal parasites can also be involved. In this chapter, we will be focusing on bacteria and viruses.

Bacteria

Bacteria are **prokaryote**, unicellular organisms with a simple internal structure. They lack a nucleus; their DNA either floats freely in the cytoplasm or is in the form of circular **plasmids**.

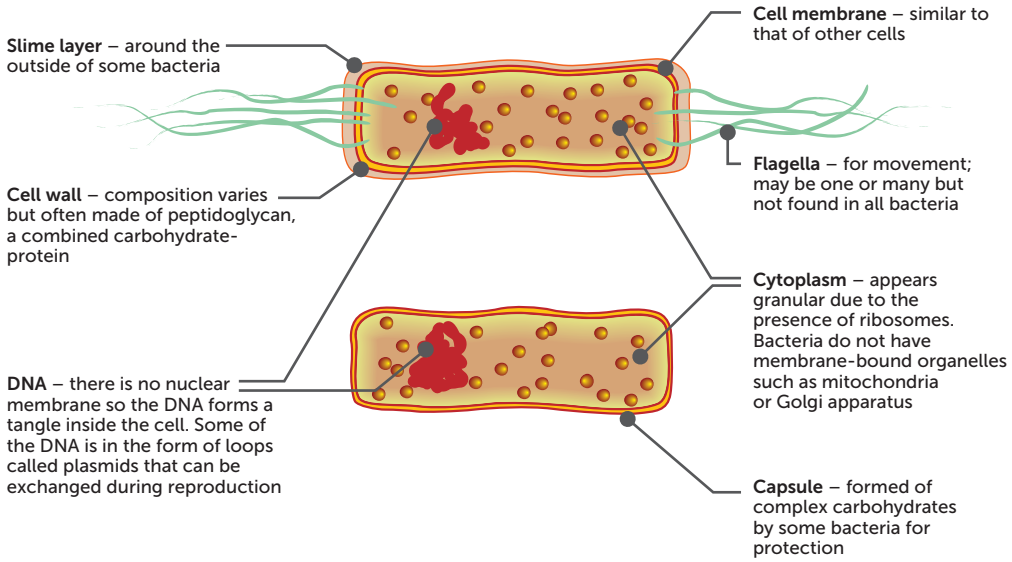

FIGURE 7.1
Structure of a typical bacterial cell

The great majority of bacteria are harmless to humans; they are non-pathogenic. Indeed, many bacteria are essential to life on Earth, through their role in the decomposition of organic material and the cycling of the elements. Some bacteria are used in industrial processes. For example, *Lactobacilli* are used to make yoghurt and sauerkraut; and the flavour of cheeses depends on the types of bacteria used in their production.

Huge numbers of bacteria live on our skin, in our alimentary canal and in other parts of the body. In the armpit of an adult male, there are more than two million bacteria per square centimetre of skin surface; and in the intestines, bacteria are so numerous that they form a major part of the digestion process. These bacteria have no ill effect on our health, yet there are others that may cause illness or death when present in relatively small numbers. Bacteria affect the body differently, depending on the species. Effects may include producing toxins or inducing an allergic response.

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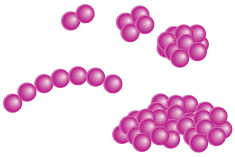
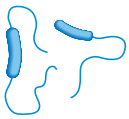
FIGURE 7.2
Types of bacteria, classified according to cell shape



Cocci (singular 'coccus') are spherical cells that may occur singly, in pairs (diplococci), in clusters (staphylococci) or in chains (streptococci)



Bacilli (singular 'bacillus') with **flagella** have rod-shaped cells; many have flagella for movement

Spirilla (singular'spirillum') have twisted cells

Vibrio are like curved rods and are often shaped like a comma

Bacteria are very small, with the average diameter ranging from 0.5 to 2.0 µm (micrometres; 1 µm = 1 x 10^{-6} m) and length ranging from 1 to 10 µm. This means that bacteria can be seen only with a microscope. Under the light microscope, about all that can be seen of bacteria is the shape of their cells, which is used to classify them.

To identify a bacterium, it is first grown on an agar plate or growth medium in specific conditions. Then it can be stained and viewed under a microscope.

a

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b

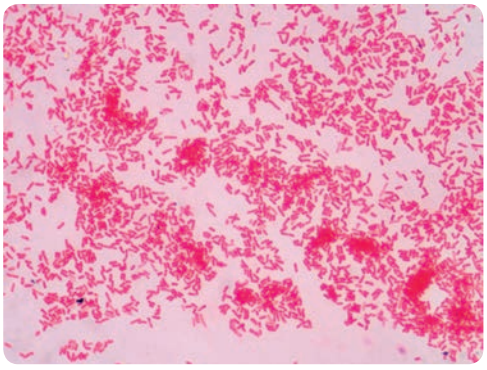

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FIGURE 7.3 a Bacteria that have invaded the body can be cultured. **b** Bacteria can be viewed under a microscope as part of their identification. Some bacteria are pink when using a gram stain technique, while others are purple.

Viruses

Activity 7.1
Investigating the effectiveness of hand washing

The discovery, by scientists such as Pasteur and Koch in the late 19th century, that some diseases were caused by bacteria was a great step forward for medical science. There were, however, certain diseases for which no bacterial cause could be found. For example, Pasteur tried in vain to find a bacterium that caused the disease rabies. We now know that the causes of these diseases are **viruses**.

Viruses are from 20 to 750nm (nanometres; 1 nm = 1 x 10^{-9} m) in size, which is too small to be seen with an ordinary light microscope. It wasn't until 1938 that scientists used an electron microscope to first see viruses. Subsequent studies showed that viruses had distinctive structures and differing sizes. All were found to contain genetic material in the form of a molecule of either DNA (deoxyribonucleic acid) or RNA (ribonucleic acid), but they never contained both. The molecule of DNA or RNA is surrounded by a coat of protein. Some viruses also have an external lipid envelope.

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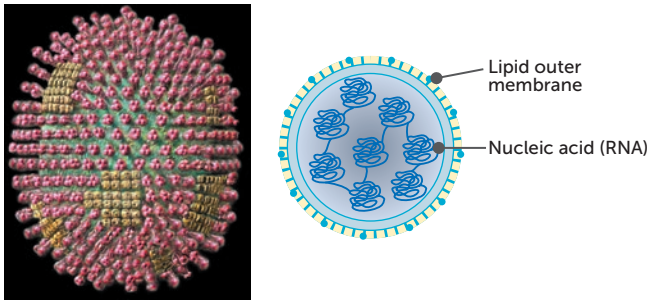
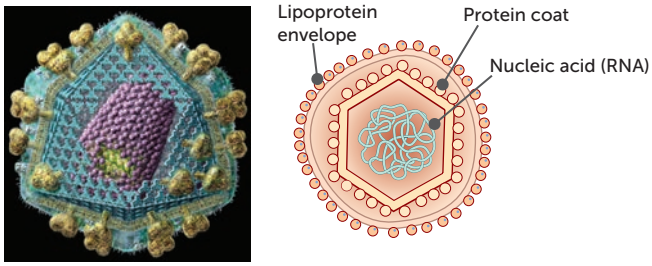


Influenza virus has a lipid outer membrane. The RNA is in eight segments.

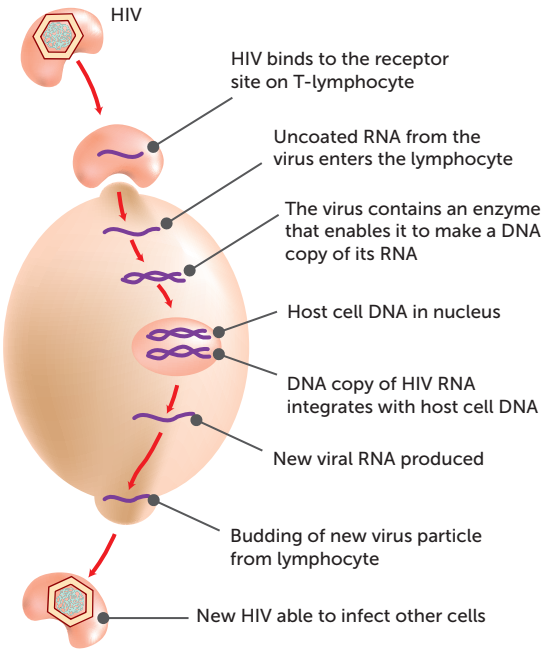


Human immunodeficiency virus (HIV) has a lipoprotein envelope with an internal protein coat.

FIGURE 7.4
Structure of the influenza virus and human immunodeficiency virus

Viruses all contain either DNA or RNA but not both. Around the nucleic acid is a protein coat, and some viruses have an additional envelope of lipid and protein molecules.

Viruses are not living things, as they cannot reproduce by themselves. Instead, they infect a living cell and its DNA or RNA induces the cell to manufacture more virus particles. The new virus particles are then able to leave the host cell to infect others. During this process the cells become damaged or changed, or die. Viruses differ in the type of cell they invade; therefore, the symptoms shown relate to the tissue that is affected. Some viruses multiply in bacterial cells, causing the death of the bacterium. Such viruses are known as **bacteriophages**.



Viruses cannot reproduce themselves. They attach to the outside of a host cell and the nucleic acid enters the cell. New viral genes are produced by the host cell, and so hundreds of new virus particles are formed.

FIGURE 7.5
The process of viral replication illustrated by HIV

Viruses
Khan Academy has more information about viruses.

ViralZone
Click on the name of the virus to view its structure.

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TABLE 7.1 Some of the better-known diseases caused by pathogens

BACTERIA	VIRUSES	FUNGI	ANIMAL PARASITES
Anthrax	HIV/AIDS	Ringworm	Protozoans
Botulism	Bird flu	Thrush	Amoebic dysentery
Bubonic plague	Chickenpox	Tinea	Amoebic meningitis
Chlamydia	Cold sores (herpes)		Malaria
Cholera	Colds		Sleeping sickness
Dental caries (tooth decay)	COVID-19		Toxoplasmosis
Diphtheria	Ebola		Platyhelminthes (flatworms)
Gastroenteritis	Encephalitis (viral)		Blood flukes
Gonorrhoea	Genital herpes		Hydatids
Impetigo (school sores)	Glandular fever		Liver flukes
Legionnaire's disease	Hepatitis A, B, C, D, E and G		Tapeworms
Leprosy	Influenza		Nematodes (round worms)
Meningitis (bacterial)	Measles		Hookworms
Peptic ulcers	Meningitis (viral)		Roundworms
Pneumonia	MERS (Middle East respiratory syndrome)		Threadworms
Scarlet fever	Mumps		Arthropods
Syphilis	Poliomyelitis		Lice
Tetanus	Rabies		Scabies (mites)
Trachoma	Ross River virus		Ticks
Tuberculosis	Rubella		
Typhoid	SARS (severe acute respiratory syndrome)		
Whooping cough	Shingles		
	Smallpox		
	Warts		
	Yellow fever		

Transmission of pathogens

Communicable disease may be spread by the transmission of the pathogenic organism from one person to another. Some communicable diseases are said to be **contagious**; this means they are passed directly from one person to another. Other communicable diseases may be spread from person to person by **vectors**; intermediate hosts of the pathogen, such as mosquitoes or fleas.

Transfer can occur in a number of ways.

- *Transmission by contact* involves the spread of the pathogen by actual physical contact. The contact may be *direct*, actually touching an infected person; or *indirect*, touching an object that has been touched by an infected individual. Skin infections and sexually transmissible infections are spread by contact.
- *Ingestion* of food or drink contaminated with pathogens may result in disease. Dysentery, typhoid fever and *Salmonella* food poisoning are transmitted in this way.
- *Transfer of body fluids* from one person to another can result in the transmission of a number of infections. When blood or other body fluids from an infected person comes into contact with the mucous membranes, such as in the nose, mouth, throat and genitals, or the bloodstream of an uninfected person, such as through a needle stick or a break in the skin, then pathogens may enter the body of that person. The human immunodeficiency virus, and hepatitis B and C, are spread in this way.
- *Infection by droplets* may occur when tiny droplets of moisture containing pathogenic organisms are emitted when breathing, talking, sneezing or coughing. The droplets may be breathed in by others, or may settle on food or utensils to be later ingested with food. Many viral infections, such as those causing Ebola, COVID-19, mumps, colds and influenza, can be spread by droplets.

Ebola in the air
This website has more information about the spread of the Ebola virus, and transmission by droplets and airborne particles.

- *Airborne transmission* of some diseases may occur. When the moisture in exhaled droplets evaporates, many bacteria are killed, but viruses and some bacteria remain viable and can cause infection when inhaled. As these particles are lighter, they remain viable for a greater distance than those transmitted by droplets. Measles and chickenpox are spread by this method.

Transmission of measles

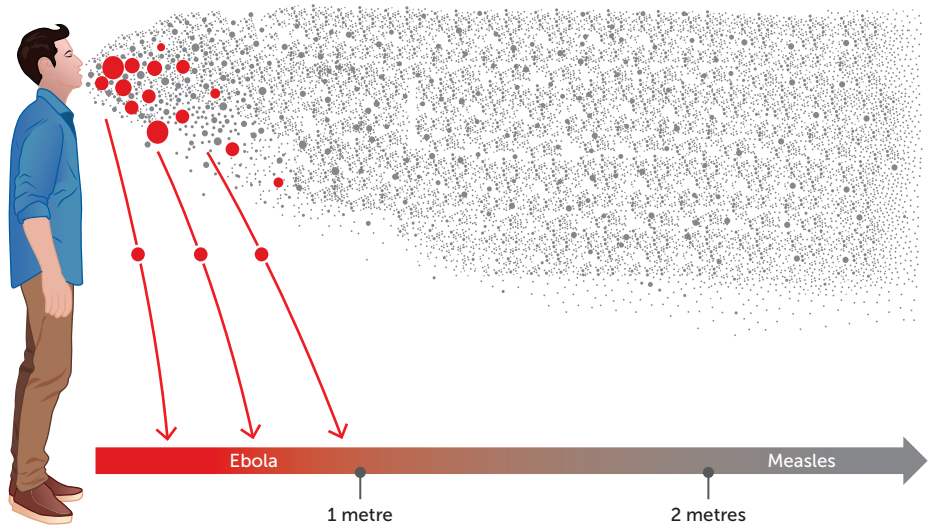


FIGURE 7.6 Transmission of pathogens by droplets (red) and airborne (grey) routes

- *Transmission by vectors* is the transfer of pathogens by other animals, such as insects, ticks or mites. Some vectors transfer the pathogen directly; others, such as house flies, may spread the pathogen to food or water, which is then ingested. Many vector-borne diseases are spread by a specific vector. For example, malaria and dengue fever are spread by mosquitoes, trypanosomiasis (African sleeping sickness) is spread by the tsetse fly, Lyme disease is spread by ticks, and bubonic plague is spread by fleas from rats and mice.

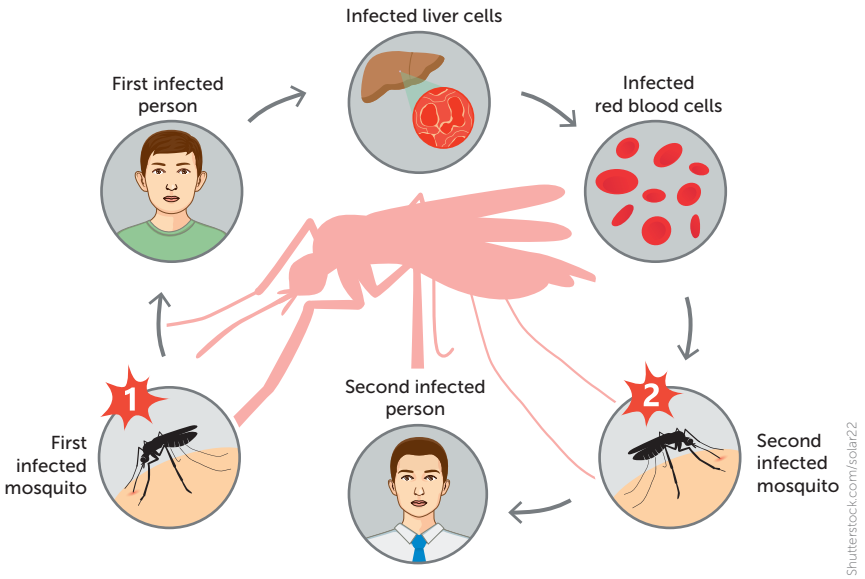


FIGURE 7.7 Transmission of malaria via a mosquito vector

Key concept

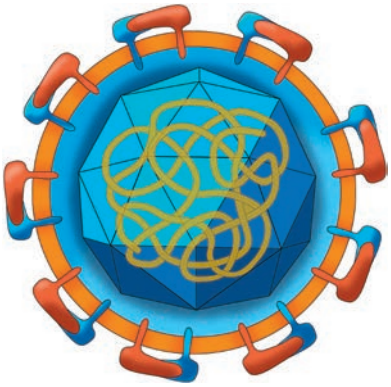
Communicable diseases are caused by pathogens such as bacteria and viruses and are spread from person to person, either directly or indirectly.

Activity 7.2
Investigating infectious disease transmission

Questions 7.1

RECALL KNOWLEDGE

1 Define 'pathogen'.
2 List the ways that a pathogen can pass from an infected person to someone else.
3 The diagram below is of the zika virus. Label the nucleic acid, protein capsule and lipid envelope.



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4 Describe the structure of a typical bacterium.
5 List the different shapes of bacteria.
6 List three vectors of pathogens and the diseases that they transmit.

APPLY KNOWLEDGE

7 During the COVID-19 pandemic, people were advised to wash their hands with soap to break down the coronavirus's protein coat. Explain how this would be effective in preventing the transmission of the virus.
8 There is some debate as to whether viruses are living things. Discuss your views on this idea.
9 It is easier to stop the transmission of pathogens that are transferred by body fluids than those that are transferred by moisture. Explain the reason for this observation.

7.2 NON-SPECIFIC DEFENCES AGAINST DISEASE

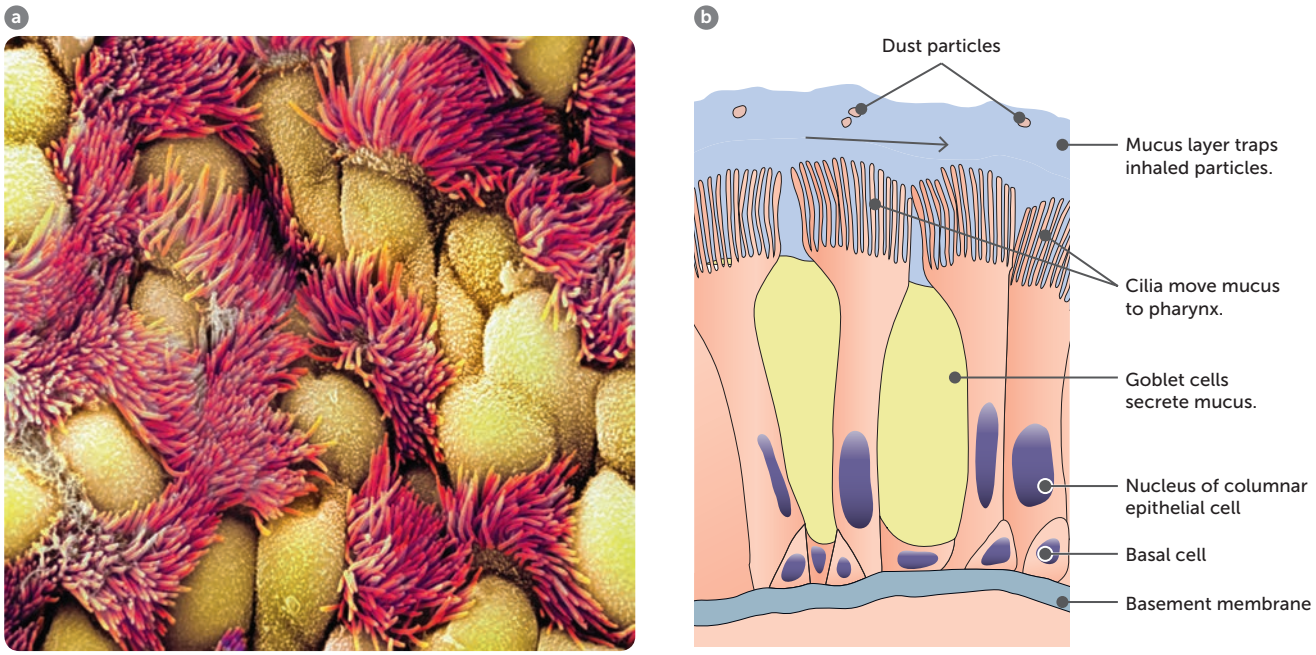
Our bodies have several defences that protect us against invasion by pathogenic micro-organisms. We are often exposed to pathogens without realising it. Many pathogens are prevented from entering the body or, if they do enter, they are dealt with before they can cause symptoms of disease. Even if we do become ill, our defence system often enables us to recover without any medical intervention.

The body's defences can be classified as specific or non-specific based on what pathogens it works against. **Non-specific defences** work against all pathogens. They are the body's first line of defence. **Specific defences** are directed at a particular pathogen.

External defences

The body has many external defences to try to stop pathogens, and other foreign particles, from entering. These are all non-specific. Some of the external defences are as follows.

- *Skin*: The skin is an effective barrier covering the outside of the body. It is very good at stopping the entry of micro-organisms, provided it is not broken by cuts and abrasions. At openings in the skin, such as the mouth, eyes and anus, special protection is provided by other defences. Huge numbers of bacteria live on the skin all the time. These normal bacteria occupy the area, and so potential pathogens find it difficult to become established. In addition, the skin has other protective mechanisms. An oily secretion called **sebum** is produced by oil glands in the skin. It contains substances that kill some pathogenic bacteria. **Sweat** secreted on to the skin contains salts and fatty acids that prevent the growth of many micro-organisms.
- *Mucus*: **Mucous membranes** line body cavities that open to the exterior. They secrete **mucus**, which traps particles and, therefore, inhibits the entry of micro-organisms to the organs of the body. The digestive, urinary and reproductive tracts are all protected in this way.
- *Hairs*: Hairs are found in the **nasal cavity** in the nose, and in the ears. In the nose, the hairs and a layer of mucus trap up to 90% of particles inhaled when breathing.
- *Cilia*: **Cilia** are tiny hair-like projections from cells that are capable of a beating motion. The mucous membranes lining the nasal cavity, the trachea and other air passages have cilia. The beating of the cilia moves mucus, containing trapped particles and micro-organisms, towards the throat, where it may be coughed up or swallowed.
- *Acids*: Stomach juices are strongly acidic. The acid kills many of the bacteria taken in with food or those contained in mucus swallowed from the nose and windpipe. The vagina also has acid secretions that reduce the growth of micro-organisms. Urine and the sweat on the skin are also slightly acidic.



Science Photo Library/NIBSC

FIGURE 7.8 a Scanning electron micrograph showing the cilia of cells lining the respiratory system; the structures between the cilia are mucus-secreting cells. **b** Mucus traps foreign particles and cilia move it out of the body.

- *Lysozyme*: **Lysozyme** is an enzyme that kills bacteria. The eyes are protected by the flushing action of tears, which contain this enzyme. Lysozyme is also found in saliva, sweat, secretions of the nose and tissue fluid.
- *Cerumen*: **Cerumen**, or ear wax, protects the outer ear against infection by some bacteria. It is slightly acidic and contains lysozyme.
- *Movement of fluid*: The flushing action of body fluids helps to keep some areas relatively free of pathogens. Urine flowing through the urethra has a cleansing action. This prevents bacterial growth and helps to stop bacteria reaching the bladder and kidneys. Women have a shorter urethra than men and so they tend to suffer more bladder infections. Tears, sweat and saliva are also involved in flushing and cleansing.

The body's external defences are summarised in Figure 7.9.

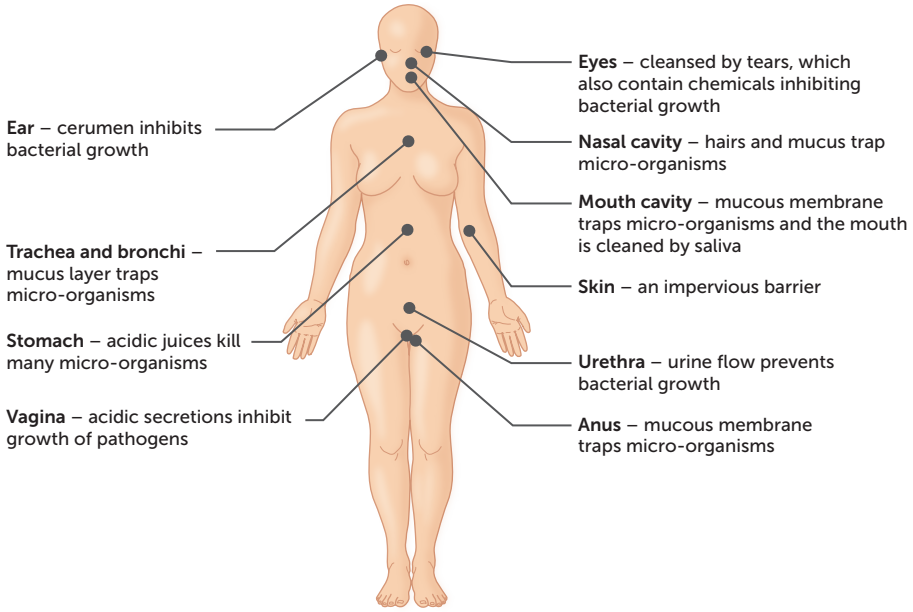


FIGURE 7.9
The body's external defences against entry of pathogenic micro-organisms

Defences against infection
This website provides an explanation of the external defences against disease.

7.1 Pathogens and non-specific immunity

Key concept

The external surfaces of the body have defence mechanisms to prevent the entry of pathogens.

Protective reflexes

A reflex is an automatic, involuntary response to a stimulus. Protective reflexes help to protect the body from injury, such as the blink reflex, or from infection, such as vomiting. Four reflexes help to protect against infection.

1. *Sneezing*: The stimulus for sneezing is irritation of the walls of the nasal cavity. The irritation may be caused by noxious fumes or dust particles, which are likely to be carrying micro-organisms. Forceful expulsion of air from the lungs carries mucus, foreign particles and irritating gases out through the nose and mouth.
2. *Coughing*: For coughing, the stimulus is irritation in the lower respiratory tract – the bronchi and bronchioles. In a manner similar to sneezing, air is forced from the lungs to try to remove the irritant. The air drives mucus and foreign matter up the trachea towards the throat and mouth.
3. *Vomiting*: Psychological stimuli, excessive stretching of the stomach and bacterial toxins can all induce vomiting. Contraction of the muscles of the abdomen and the diaphragm, not the contraction of the stomach, expels the stomach contents.

4 *Diarrhoea*: Irritation of the small and large intestines by bacteria, viruses or protozoans can cause diarrhoea. The irritation causes increased contractions of the muscles of the wall of the intestines so that the irritant is removed as quickly as possible. Material does not stay in the large intestine long enough for water to be absorbed, so the faeces are very watery.

Key concept

Protective reflexes such as sneezing, coughing, vomiting and diarrhoea remove foreign particles in an automatic, involuntary response.

Internal non-specific defences

If pathogens get past our external defences, there are internal non-specific defences that work to eliminate them.

Phagocytosis

Organisms that penetrate our external defences are attacked by phagocytes. **Phagocytes** are specialised white blood cells, or **leucocytes**, that engulf and digest micro-organisms and cell debris. This eliminates many pathogens before an infection has a chance to take hold.

There are a number of different types of cells that are phagocytic.

1 *Monocytes and macrophages*: When a tissue becomes infected or inflamed, **monocytes** leave the bloodstream and enter the tissue. Here they differentiate into **macrophages**, which are large phagocytic cells. Some macrophages move through the tissues looking for and destroying pathogens. Others are fixed in one place and only deal with the pathogens that come to them. Macrophages are particularly important in removing microbes and dying cells through phagocytosis.

2 *Neutrophils*: **Neutrophils** are described as a granulated leucocyte, due to the granules visible in their cytoplasm. They are also characterised by their lobulated nucleus.

Neutrophils are the most abundant leucocyte, accounting for 55–70% of all leucocytes. During an infection, neutrophils are the first cells to move into the tissue to destroy the pathogen by phagocytosis. They are particularly important in killing pathogens inside cells.

Neutrophils have a short life span and die after a few days. The dead cells make up a large portion of the pus that forms after an infection.

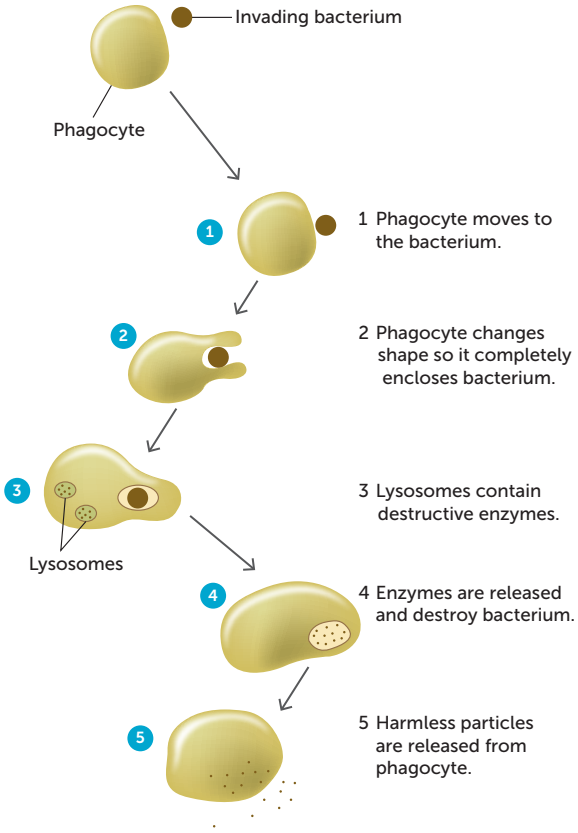


FIGURE 7.10 The process of phagocytosis

Phagocytosis
This website provides an animation of phagocytosis.

Licking wounds helps healing
This article explains why licking a wound helps it to heal faster.

Phagocytes
This website has further information about phagocytosis.

Types of leucocytes
These websites contain information about the different types of leucocytes and their functions.

3 *Dendritic cells*: **Dendritic cells** are characterised by projections from the cytoplasm. They are slightly different from macrophages and neutrophils in that their function goes beyond just phagocytosis. These cells have the ability to detect, engulf and process foreign particles. They then use information about the ingested particles to assist with specific immunity. You will learn more about dendritic cells later in this chapter.

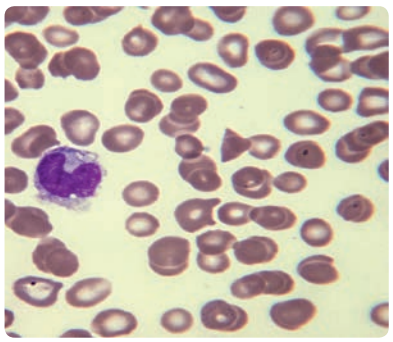


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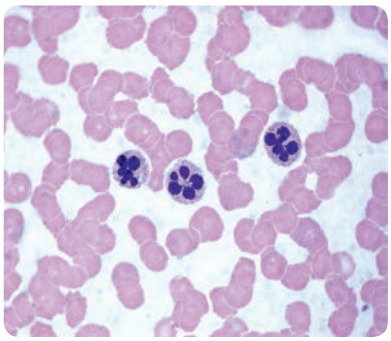
FIGURE 7.11 Monocytes have a kidney bean-shaped nucleus



iStock.com/Jose Luis Calvo Martin & Jose Enrique Garcia-Maurino MUZQUIZ

FIGURE 7.12 Neutrophils have a granular cytoplasm and a lobulated nucleus

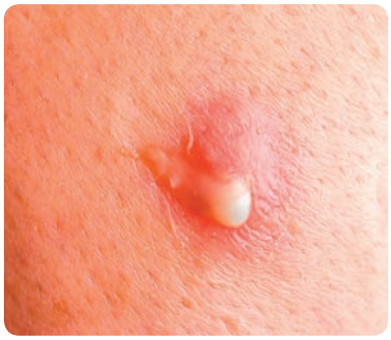


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FIGURE 7.13 Pus forms following an infection

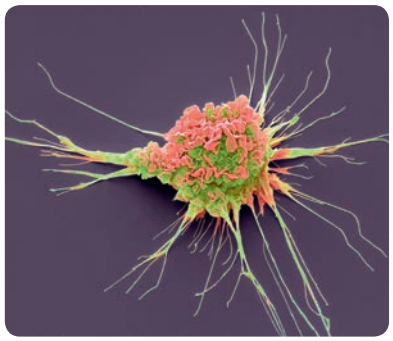

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FIGURE 7.14 Scanning electron micrograph (SEM) showing a dendritic cell with its extensions from the cytoplasm

Key concept

Macrophages, neutrophils and dendritic cells are phagocytes that engulf and destroy debris and pathogens.

Inflammatory response

Inflammation
This website provides an animation of the process of inflammation.

Words ending in *-itis* indicate **inflammation** of specific organs or tissues. For example, tonsillitis is inflammation of the tonsils; meningitis is inflammation of the meninges, the membranes around the brain; and laryngitis is inflammation of the larynx.

Inflammation is a response to any damage to the tissues. The purpose of inflammation is to:

- reduce the spread of any pathogens, to destroy them and to prevent the entry of additional pathogens
- remove damaged tissue and cell debris
- begin repair of the damaged tissue.

There are four signs of inflammation. If you think of an infected cut, a pimple or a mosquito bite, you will be able to identify each of the four signs of redness, swelling, heat and pain.

Damage to tissues stimulates a series of steps in the inflammatory response. Some of these steps are assisted by proteins in the **complement system** that are produced by liver cells and macrophages. The complement system is a series of more than 20 proteins, many of which are normally inactive. When initiated, one protein activates the next, which activates the next, and so on.

The steps of the inflammatory response include:

1. Mechanical damage or local chemical changes cause specialised leucocytes called **mast cells** to be activated by complement proteins. This results in the release of histamine, heparin and other chemicals into the tissue fluid.
2. **Histamine** increases blood flow through the area due to **vasodilation**, making the walls of the blood capillaries more permeable. More fluid moves through the capillary walls into the tissue. The increased blood flow causes heat and redness, and the escape of fluid from the blood causes swelling.
3. **Heparin** prevents clotting, so the release of heparin from the mast cells prevents clotting in the immediate area of the injury. A clot of the fluid forms around the damaged area, which slows the spread of the pathogen into healthy tissues.
4. Complement system proteins and some chemicals released by the mast cells attract phagocytes, particularly neutrophils, which actively consume micro-organisms and debris by phagocytosis.
5. The abnormal conditions in the tissue stimulate pain receptors, and so the person feels pain in the inflamed area.
6. The phagocytes, filled with bacteria, debris and dead cells, begin to die. The dead phagocytes and tissue fluid form a yellow liquid called pus.
7. New cells are produced by mitosis, and repair of the damaged tissue takes place.

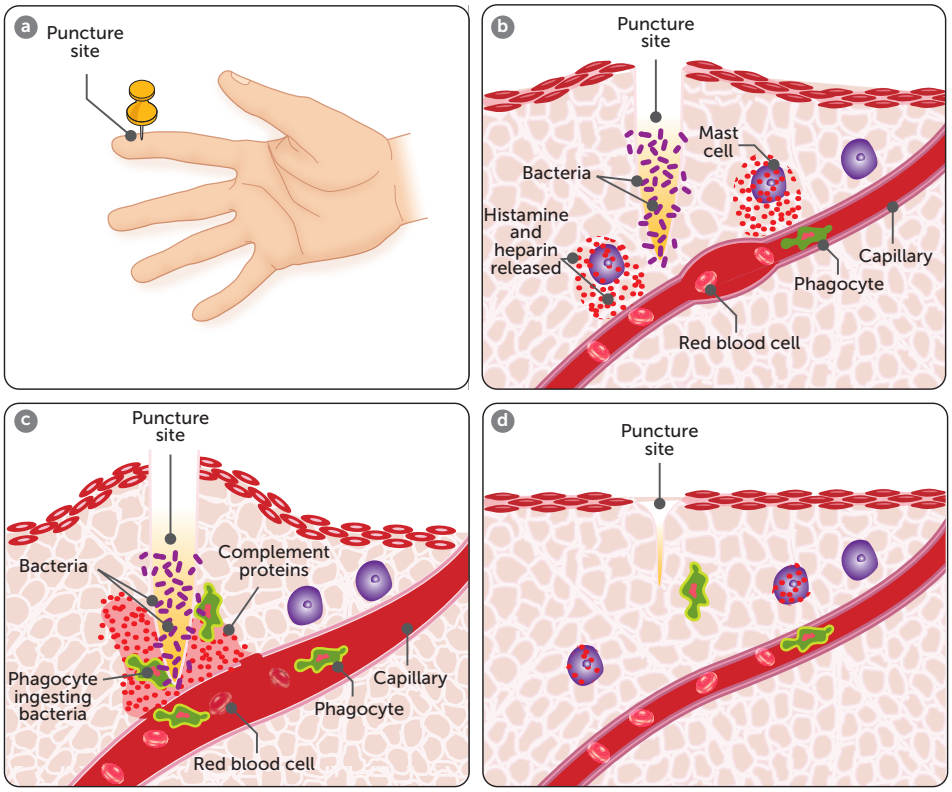

FIGURE 7.15 The inflammatory response: **a** When the skin is broken, a non-specific inflammatory response is triggered. **b** Mast cells release histamine and heparin. Histamine diffuses into capillaries, causing them to dilate and become leaky. The area becomes red and swollen. Heparin prevents clotting in the immediate area. **c** Complement proteins are activated and, along with chemicals from the mast cells, attract phagocytes to the area, which engulf and digest dead cells and bacteria. **d** The tissue heals when histamine and protein signalling finish and phagocytes are no longer attracted to the area

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Key concept

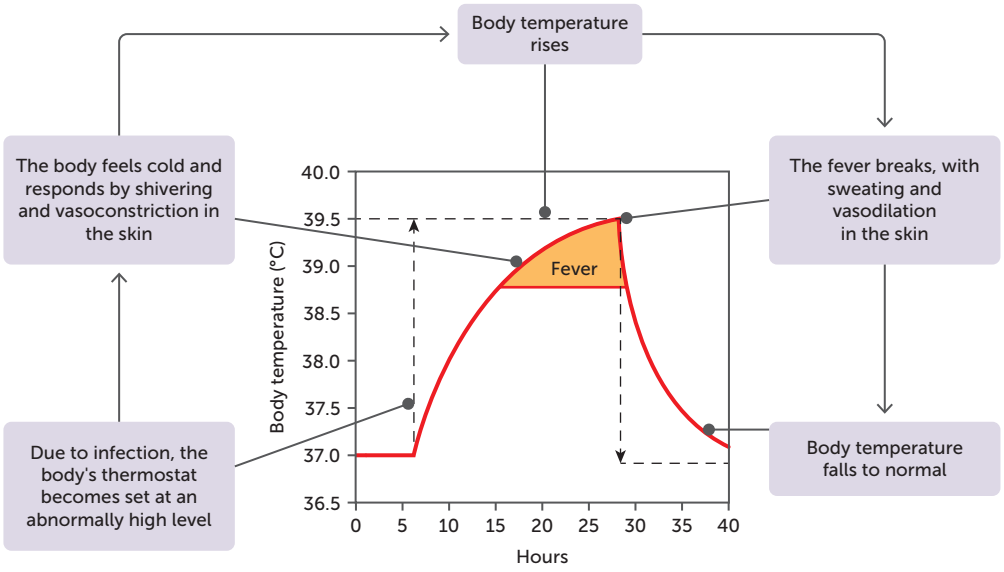
Inflammation occurs when tissue is damaged or infected. Increased blood flow, blood vessel permeability and phagocytosis lead to heat, redness, swelling and pain.

Fever

An infection such as the common cold or influenza is frequently accompanied by an elevation of body temperature, often called a **fever**. The change in body temperature is due to a resetting of the body's thermostat, controlled by the hypothalamus, to a level higher than normal. This reaction is thought to be due to chemicals called **pyrogens** that are released by white blood cells during the inflammatory response and act on the hypothalamus. One pyrogen is **interleukin-1**. It is predominantly produced by activated macrophages, but is also produced by other cells such as dendritic and epithelial cells. When a person has a fever, the body temperature is still regulated in response to heat or cold, but the set point is at a higher level.

The onset of fever is frequently gradual, but it is most striking when it occurs rapidly. In these cases, it is as though the body's thermostat were suddenly raised. The person's thermoreceptors detect the body temperature, and the hypothalamus recognises that it is lower than the new, higher set point. As a consequence, vasoconstriction in the skin and shivering occur. Both these activities conserve heat and increase heat production, driving the body temperature up rapidly. When the fever breaks, the point called the crisis, it is as though the body's thermostat has been reset to normal. In this situation the person feels hot and appears flushed, as skin vasodilation and profuse sweating take place.

FIGURE 7.16
Body temperature during fever



Fever is beneficial, up to a point. High body temperature is believed to inhibit the growth of some bacteria and viruses. In addition, heat speeds the rate of chemical reactions, which may in turn help body cells repair themselves more quickly during a disease. Fever may also inhibit viral replication by allowing chemicals called **interferons** to operate more quickly. However, if the body temperature goes too high it can cause convulsions and brain damage. Generally speaking, death will result if the body temperature reaches 44.4–45.5°C.

Activity 7.3
Plotting a fever

Key concept

Fever occurs when the body's set point for temperature is increased due to pyrogens acting on the hypothalamus. Fever can help fight infections but is dangerous if it goes too high.

Lymphatic system

The **lymphatic system** consists of:

- a network of lymph capillaries joined to larger lymph vessels
- lymph nodes, which are located along the length of some lymph vessels.

The main function of the lymphatic system is to collect some of the fluid that escapes from the blood capillaries and return it to the circulatory system. In addition to this main function, the lymphatic system is an important part of the body's internal defence against pathogenic organisms. The lymphatic system was discussed in Chapter 5 of *Human Perspectives ATAR Units 1 & 2*.

Lymph nodes occur at intervals along the lymphatic vessels. Each node contains masses of lymphoid tissue, the cells of which are criss-crossed by a network of fibres. Lymph entering the lymph nodes contains cell debris, foreign particles and micro-organisms that have penetrated the body's external defences. Some of these micro-organisms may be pathogenic and, if not destroyed, could cause disease. Larger particles, such as bacteria, are trapped in the meshwork of fibres as the lymph flows through the spaces in the nodes. Macrophages ingest and destroy these particles by phagocytosis.

When infections occur, the formation of lymphocytes increases, and the lymph nodes become swollen and sore. For example, an infected finger may result in swelling and tenderness in the armpit, where there are a large number of lymph nodes. Most lymphocytes are important in the specific immune response to a particular pathogen.

Questions 7.2

RECALL KNOWLEDGE

1. Define 'non-specific defences'.
2. Explain why the skin is such an effective external defence to infection.
3. Describe the role of cilia in the external defence mechanisms.
4. List the parts of the body that use acids to protect against disease.
5. List five protective reflexes that protect against disease or injury.
6. Name three cells that are phagocytes in tissue.
7. Draw a series of diagrams to show phagocytosis.
8. List the signs of inflammation.
9. Which cells release heparin and histamine following tissue damage?
10. Define 'fever' and 'pyrogen', and explain their relationship.
11. Name one pyrogen.
12. What is the benefit of fever during an infection?
13. Describe how lymph nodes provide non-specific defence against disease.

APPLY KNOWLEDGE

14. Explain why it is common to cough after being in a dusty environment.
15. Explain why the incidence of urinary tract infections is higher in females than in males.
16. Suggest what nephritis is.
17. Compare and contrast macrophages and neutrophils.
18. Explain how histamine causes swelling during inflammation.
19. When people are sick, they often feel cold even though their body temperature may be above normal. Explain why this happens.
20. During the COVID-19 pandemic, it was compulsory in many places to wear a mask when in public. Explain how a mask could reduce the transmission of the virus.
21. Traditionally, it was common practice to cover your mouth with your hand when coughing. Recently, it is recommended that you cough into your elbow or shoulder. Explain why this method could be more beneficial in preventing the transmission of disease.

7.3 SPECIFIC DEFENCES AGAINST DISEASE

Specific defences are those directed towards a particular pathogen. For example, if you get infected (or vaccinated) with chickenpox virus, the body will make antibodies to combat that virus. Those antibodies are only effective against chickenpox virus and will not work against any other virus or bacterium.

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Specific defences are part of our immune system. The **immune system** is composed of cells and proteins that protect against foreign organisms, a range of alien chemicals, as well as cancerous and other abnormal cells. Some of these cells are non-specific, such as phagocytes, which are able to engulf and digest micro-organisms and cell debris. However, others such as B-cells and T-cells only provide protection against a specific micro-organism or disease-causing substance. When these cells react, it is called the **immune response**.

Immune response

The immune response is a homeostatic mechanism. When micro-organisms or foreign substances enter the body, the immune response helps to deal with the invasion and restore the internal environment to its normal condition.

The key cells involved in the immune response are **B-cells** and **T-cells**, which are white blood cells called **lymphocytes**. B-cells and T-cells are both produced in the bone marrow and end up in the **lymphoid tissue**. However, they mature by different routes. About half the cells produced by the bone marrow go to the thymus, where they mature into T-cells before being incorporated into the lymphoid tissues. The other half of the cells mature in the bone marrow to become B-cells and then become part of the lymphoid tissues. Most of the lymphoid tissue is in the lymph nodes; however, it also occurs in other parts of the body, such as the spleen, thymus gland and tonsils.

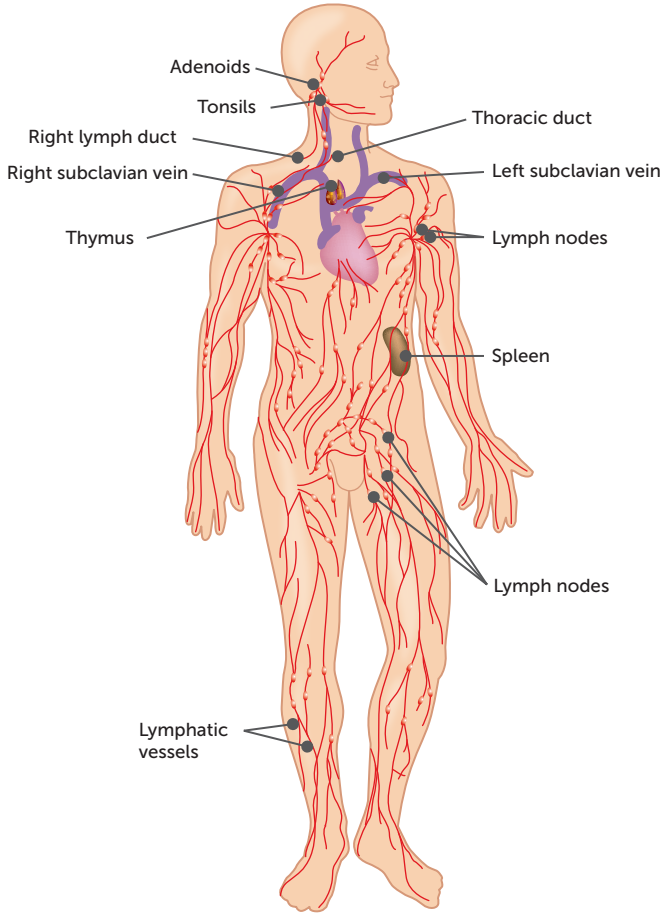

FIGURE 7.17
Lymphoid tissue occurs throughout the body

There are two parts to the immune response.

- The **humoral response** or **antibody-mediated immunity** involves the production of special proteins called antibodies by B-cells, which circulate around the body and attack invading agents.
- The **cell-mediated response** is due to T-cells and involves the formation of special lymphocytes that destroy invading agents.

Antigens

Antibody-mediated and cell-mediated immunity are both triggered by antigens. An **antigen** is any substance capable of causing a specific immune response. They are large molecules such as proteins, carbohydrates, lipids or nucleic acids and may include (among others):

- virus particles
- whole micro-organisms, such as a bacterial cell
- part of a bacterium, such as the flagella, cell wall or capsule
- toxins
- molecules on cells such as blood cells
- pollen grains
- egg whites.

Large molecules produced in a person's own body do not cause an immune response. These are called **self-antigens**. Foreign compounds that do trigger an immune response are **non-self antigens**. The immune system becomes programmed before birth to distinguish between self-antigens and non-self antigens. From then on, it only attacks non-self antigens.

Key concept

Antigens are capable of producing an immune response.

Antibodies

An **antibody** is a Y-shaped specialised protein that is produced by **plasma cells** in response to a non-self antigen. Antibodies belong to a group of proteins known as **immunoglobulins**, often represented as 'Ig'. There are five classes of antibodies, which vary in their structure and are designated IgA, IgD, IgE, IgG and IgM.

The antibody produced in response to an antigen can combine with that antigen to form an **antigen–antibody complex**. Antigen molecules have specific active sites with a particular shape. The antibody has the complementary shape, allowing the two molecules to fit together like a key in a lock. Each antibody can combine with only one particular antigen, in the same way that a key will only open a particular lock.

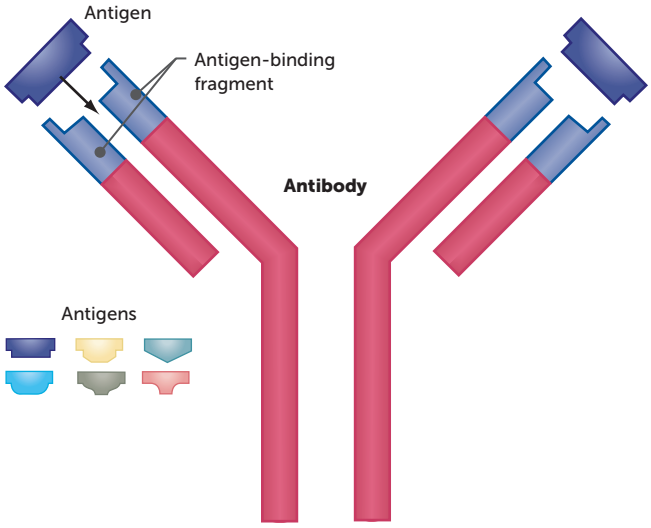

FIGURE 7.18
The active sites on the antibody and antigen molecules are complementary: they fit together like a lock and key

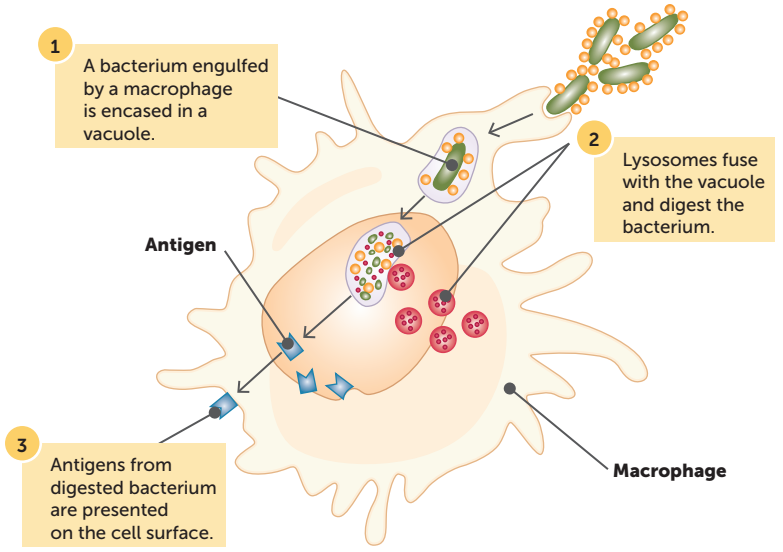

FIGURE 7.19 Antigen-presenting cells, such as macrophages, detect, engulf and digest pathogens to present the antigens to lymphocytes.

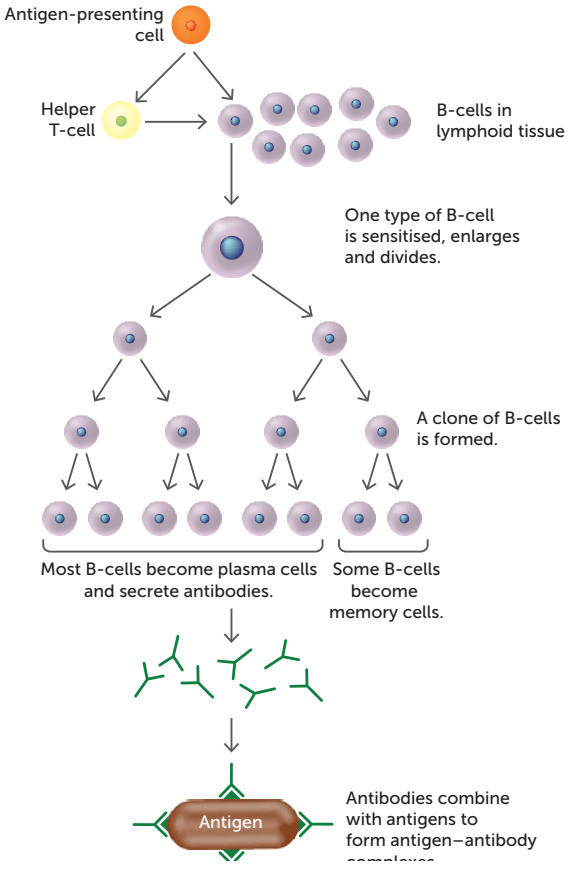

FIGURE 7.20 Events in the antibody-mediated immune response

Antigen-presenting cells

When a non-self antigen enters a body, specific cells recognise this and respond appropriately. These cells are called **antigen-presenting cells**, and include dendritic cells, macrophages and undifferentiated B-cells. These cells:

- detect the presence of a non-self antigen
- engulf the pathogen
- digest the pathogen, producing small fragments that move to the surface of the cell
- present the antigen to lymphocytes.

Antibody-mediated immunity

The humoral response involves the production and release of antibodies into the blood and lymph. This is antibody-mediated immunity. It provides resistance to viruses, bacteria and bacterial toxins before these micro-organisms or substances enter the body's cells.

Lymphoid tissue contains thousands of types of B-cells. Each type has a receptor for a particular antigen and, therefore, is capable of responding to a specific antigen. When an antigen-presenting cell presents the antigen to the specific B-cells, the B-cells are activated. The antigen is also present to helper T-cells, leading to the release of **cytokines**, small proteins that are released in response to antigens and act as messengers in the immune response. These cytokines cause the helper T-cells to clone themselves to release different cytokines, which activate the B-cells.

When the B-cells are activated, they enlarge and divide into a group of cells called a **clone**. Most of the clone becomes plasma cells, which secrete the specific antibody capable of attaching to the active site of the antigen. These antibodies circulate in the blood, lymph and extracellular fluid to reach the site of the invasion of micro-organisms or foreign material. The remaining B-cells of the clone become **memory cells**. Memory cells spread to all body tissues to allow the response to occur more rapidly should the antigen enter the body again.

On the first exposure to an antigen the immune reaction is called the **primary response**. The body's immune system usually responds fairly slowly, often taking several days to build up large amounts of antibodies. This is because it takes time for the B-cells to multiply and differentiate into plasma cells and then secrete antibodies. Once the level of antibodies reaches a peak, it begins to decline. However, the primary response leaves the immune system with a memory of that particular antigen.

With a second or subsequent exposure to the same antigen, the response is much faster due to memory cells recognising the antigen more quickly. With this **secondary response**, plasma cells are able to form very quickly, with antibody levels in the blood plasma rising rapidly to a higher level that lasts longer. Frequently, this response is so quick that the antigen has little opportunity to exert any noticeable effect on the body and no illness results.

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How antibodies work

Different antibodies protect the body by different methods. They may:

- inactivate foreign enzymes or toxins by combining with them or inhibiting their reaction with other cells or compounds
- bind to the surface of viruses and prevent them entering cells
- coat bacteria so that they are more easily consumed by phagocytes
- cause particles such as bacteria, viruses or foreign blood cells to clump together, a process known as **agglutination**
- dissolve organisms
- react with soluble substances to make them insoluble and thus more easily consumed by phagocytes.

Figure 7.24 summarises the action of antibodies.

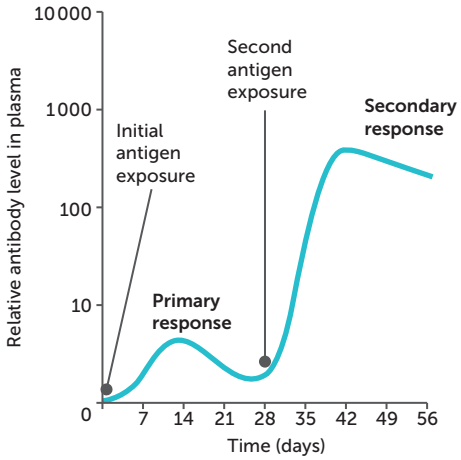
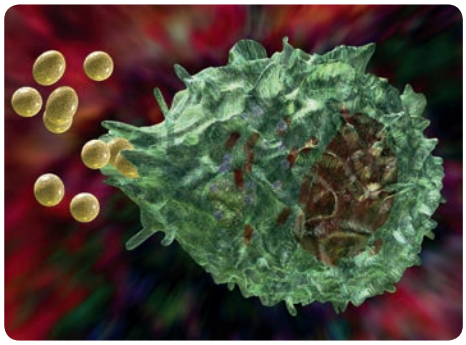
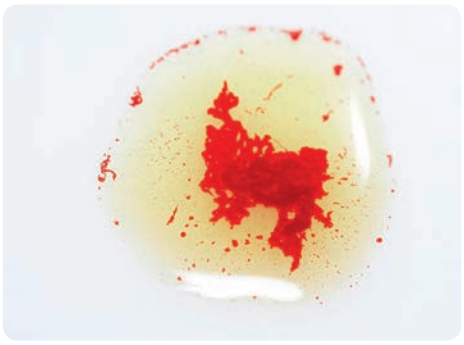


FIGURE 7.21 The antibody level in blood plasma after a first and second exposure to an antigen



Science Photo Library/Russell Kightley

FIGURE 7.22 A macrophage (green) engulfing bacteria (yellow) by the process of phagocytosis



Science Photo Library/CCHASSENET

FIGURE 7.23 Agglutination of red blood cells due to the presence of antibodies for the antigens on the surface of the cells

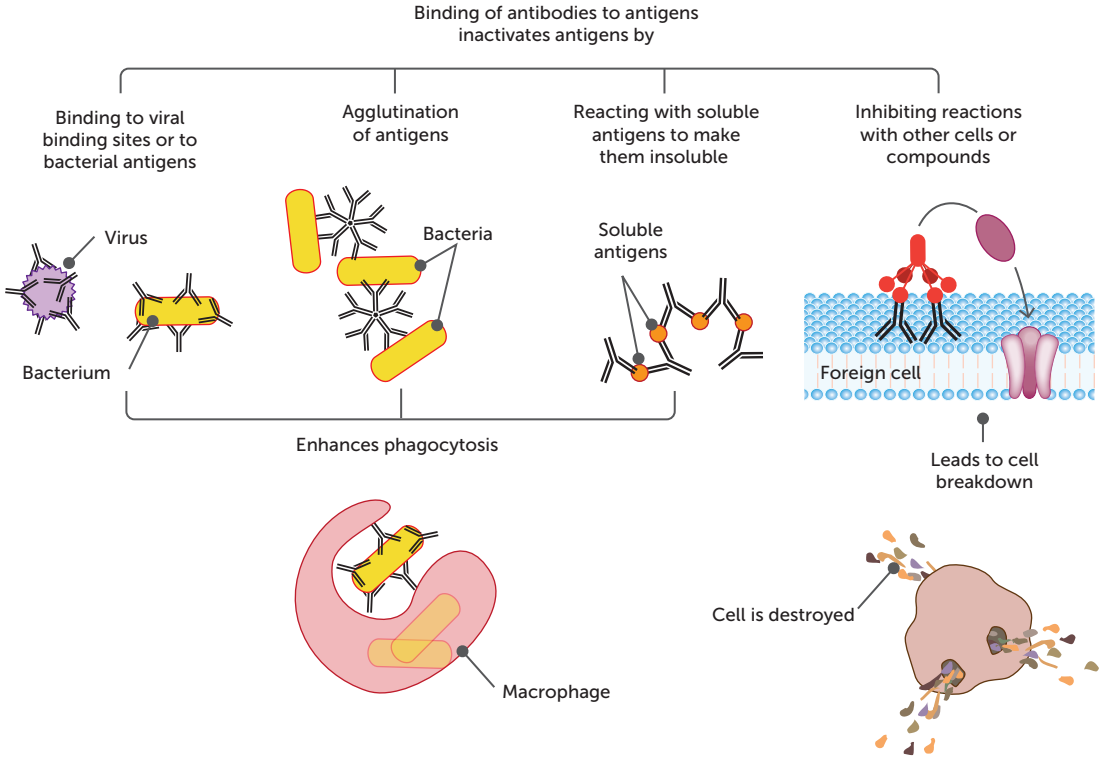


FIGURE 7.24 Summary of how antibodies interact with antigens to inactivate the antigens

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Immune response
This website provides an animated sequence showing the immune response.

Key concept

Antibody-mediated immunity occurs when B-cells are stimulated, resulting in the production of antibodies and memory cells.

Cell-mediated immunity

Cell-mediated immunity provides resistance to the intracellular phase of bacterial and viral infections. These pathogens, such as the bacteria responsible for tuberculosis and Legionnaire's disease, specialise in invading and replicating inside their hosts' own cells, making them particularly difficult to overcome.

Cell-mediated immunity is also important in 'fighting' whole cells, such as providing resistance to fungi and parasites, and in rejecting foreign-tissue transplants. It also appears to be important in fighting cancer cells.

The T-lymphocytes are responsible for cellular immunity. They occur in the same lymphoid tissue as B-cells but occupy different areas of the tissue. Like B-cells, there are thousands of types of T-cells, and each type responds only to one particular antigen. When a foreign antigen such as a virus or a bacterium enters the body, the antigen-presenting cells present the antigen to the particular type of T-cells. These become activated or sensitised.

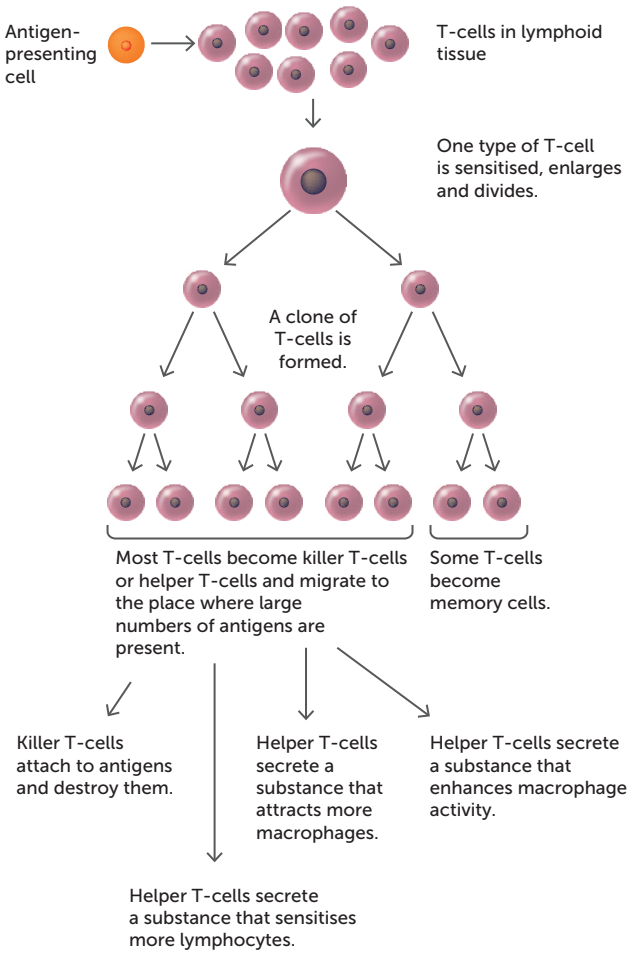

FIGURE 7.25 Response to T-cells in cell-mediated immunity

The sensitised T-cells enlarge and divide, each giving rise to a clone, a group of identical T-cells. Some cells of the clone remain in the lymphoid tissue as memory cells, which are able to quickly recognise the original invading antigen. If infection with the same antigen should occur again, these memory cells can initiate a much faster response to the second and subsequent infections.

The T-cells that do not become memory cells develop further, producing three different types of T-cell.

1. **Killer T-cells** (also known as **cytotoxic T-cells**) migrate to the site of infection and deal with the invading antigen. They attach to the invading cells and secrete a chemical that will destroy the antigen, and then go in search of more antigens.
2. **Helper T-cells** play an important role in both humoral and cellular immunity. They bind to the antigen on antigen-presenting cells, stimulating the secretion of cytokines that:
   - attract lymphocytes to the infection site which become sensitised and activated, thus intensifying the response

- attract macrophages to the place of infection so that the macrophages can destroy the antigens by phagocytosis
- intensify the phagocytic activity of macrophages
- promote the action of killer T-cells.

3 **Suppressor T-cells** act when the immune activity becomes excessive or the infection has been dealt with successfully. They release substances that inhibit T- and B-cell activity, slowing down the immune response.

Key concept

Cell-mediated immunity occurs when T-cells are stimulated, resulting in the production of killer T-cells and helper T-cells as well as memory cells.

TABLE 7.2 Summary of immune responses

ANTIBODY-MEDIATED IMMUNITY (HUMORAL IMMUNITY)	CELL-MEDIATED IMMUNITY (CELLULAR IMMUNITY)
Works against bacteria, toxins and viruses before they enter the body's cells; also against red blood cells of a different blood group than the person.	*Works against transplanted tissues and organs, cancer cells and cells that have been infected by viruses or bacteria; also provides resistance to fungi and parasites.*
1 Antigen-presenting cells recognise, engulf and digest pathogens, displaying the antigen on their surface.	1 Antigen-presenting cells recognise, engulf and digest pathogens, displaying the antigen on their surface.
2 Antigen-presenting cells reach lymphoid tissue and present the antigen to lymphocytes.	2 Antigen-presenting cells reach lymphoid tissue and present the antigen to the lymphocyte.
3 Helper T-cells are stimulated by antigen-presenting cells, which release cytokines.	3 Helper T-cells are stimulated by antigen-presenting cells, which release cytokines.
4 Specific B-lymphocytes are stimulated to undergo rapid cell division.	4 Specific T-lymphocytes are stimulated to undergo rapid cell division.
5 Most new B-cells develop into plasma cells, which produce antibodies and release them into blood and lymph.	5 Most new T-cells develop into killer T-cells or helper T-cells, which migrate to the site of the infection.
6 Antibodies combine with the specific antigen and inactivate or destroy it.	6 Killer T-cells destroy the antigen, while helper T-cells promote phagocytosis by macrophages.
7 Some of the new B-cells form memory cells.	7 Some sensitised T-cells form memory cells.

Immune response
This website includes an animation of a B-cell and a T-cell attacking an invader.

Types of immunity

Immunity is resistance to infection by invading micro-organisms. The presence of memory cells allows the body to respond quickly enough to deal with any invasion by pathogenic micro-organisms before symptoms of disease occur. The ability to respond rapidly may be natural or artificial. **Natural immunity** occurs without any human intervention; **artificial immunity** results from giving people an antibody or antigen.

Natural and artificial immunity can be passive or active.

Passive immunity

Passive immunity is when a person receives antibodies produced by someone else, meaning that the individual's body plays no part in the production of antibodies. This can occur naturally when antibodies from the mother pass across the placenta to a developing foetus or when the mother's antibodies are passed to the baby in breast milk. It can also be gained artificially when a person is injected with antibodies to combat a particular infection. This is often done when a person is exposed to pathogens that cause serious diseases, such as tetanus, diphtheria and rabies. Antibodies are given so that immunity is established immediately. Passive immunity is short-lived: it lasts only until the antibodies are broken down and excreted.

Active immunity

Active immunity results when the body is exposed to a foreign antigen and manufactures antibodies in response to that antigen. While the amount of antibody decreases, this type of immunity lasts longer than passive immunity due to the presence of memory cells. Should a subsequent infection involving the same antigen occur, the appropriate antibodies can be produced very quickly, eliminating the antigen before the infection can produce any disease symptoms. Active immunity to a disease can develop from having the disease and recovering (natural active immunity) or from an injection of the antigens associated with the disease (artificial active immunity).

Table 7.3 summarises the types of immunity.

TABLE 7.3 Types of immunity

	NATURAL	ARTIFICIAL
Passive	Antibodies enter the bloodstream across the placenta or in breast milk.	Antibodies are injected into the bloodstream.
Active	Ability to manufacture antibodies results from an attack of a disease.	Ability to manufacture antibodies results from being given an antigen by vaccination.

Key concept

Immunity is due to memory cells that react very quickly when exposed to the specific antigen. It may be passive or active, and be gained naturally or artificially.

Questions 7.3

RECALL KNOWLEDGE

1. Define 'specific defences'.
2. Name the two types of lymphocytes, and state where each is produced and becomes mature.
3. Which type of lymphocyte is responsible for cell-mediated immunity?
4. Define 'antigen' and describe its role in specific defences.
5. Describe the structure of an antibody.
6. Describe the series of events that occur during antibody-mediated immunity.
7. List the ways that an antigen–antibody complex stops an infection.
8. Describe the function of helper T-cells, killer T-cells and suppressor T-cells.
9. Describe how immunity can be classified based on the method of gaining:
   a. antibodies
   b. immunity.

APPLY KNOWLEDGE

10. Draw a flow chart to show how the immune response is a homeostatic response.
11. People whose blood type is A have the A antigen on their red blood cells.
    a. Explain why they may contain B antibodies in the plasma.
    b. Suggest what might happen if they are given red bloods cells of blood type B or AB.
    c. Explain why red blood cells of blood type O are safe to receive.
    d. Explain why, if a plasma transfer is needed, the preferred type is A and not O.
12. Why is the secondary response quicker and longer lasting than the primary response?
13. Even though we consider the cell-mediated and humoral responses separately, there is some overlap. Discuss this overlap.
14. For each situation below, state whether the humoral response or cell-mediated response would be more important.
    a. A heart transplant
    b. A viral infection
    c. A blood transfusion
    d. Tetanus toxins
    e. A bacterial skin infection
    f. A fungal infection.
15. Explain why vaccination leads to an active, artificial immunity, while breast milk produces a passive, natural immunity in a baby.

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7.4 PREVENTION AND TREATMENT OF DISEASE

Understanding disease, and our body's response to it, allows us to develop methods of preventing and treating it.

Vaccines

Immunisation means programming the immune system so that the body can respond rapidly to infecting micro-organisms. In other words, it is developing an immunity. This can occur naturally or artificially. **Vaccination** is the artificial introduction of antigens of pathogenic organisms so that the ability to produce the appropriate antibodies is acquired without the person having to suffer the disease. Thus, there is a slight difference in meaning between 'vaccination' and 'immunisation', but the two words tend to be used interchangeably.

A **vaccine** is the antigen preparation used in artificial immunisation. Traditional vaccines are of four types.

- *Live attenuated vaccines*: Living **attenuated** micro-organisms are micro-organisms of reduced **virulence**; that is, micro-organisms with a reduced ability to produce disease symptoms. Therefore, the immunised person does not contract the disease but manufactures antibodies against the antigen. Vaccines containing living attenuated micro-organisms include those for immunisation against polio, tuberculosis, rubella (German measles), measles, mumps and yellow fever.

Science Photo Library/James King-Holmes

FIGURE 7.26 Vaccines for some viral diseases are produced by allowing the viruses to multiply in living cells: here the influenza virus is being introduced into fertile eggs

TABLE 7.4 Deaths from diseases commonly vaccinated against, Australia, 1926–2016

PERIOD	DIPTHERIA	PERTUSSIS	TETANUS	POLIOMYELITIS	MEASLES	POPULATION ESTIMATE (MILLION)
1926–1935	4073	2808	879	430	1102	6.60
1936–1945	2791	1693	655	540	822	7.20
1946–1955	624	429	625	1091	495	8.60
1956–1965	44	58	280	176	210	11.00
1966–1975	11	22	82	61	146	13.75
1976–1985	2	14	31	70	62	14.90
1986–1995	2	9	21	69	36	17.30
1996–2005	0	9	7	140	1	18.73
2006-2016	3	36	7	183	2	20.80

Source: AIHW: Vaccine-preventable diseases fact sheets, data tables, November 2018. Australian Institute of Health and Welfare (AIHW) CC-BY 3.0.

Note 1: Shading indicates decade in which community vaccination started for the disease.

Note 2: Since the widespread introduction of the polio vaccine in the 1950s, death caused by polio has been rare. The majority (89%) of polio deaths after 1996 were in people aged 65 and older and were likely due to the after-effects of a previous infection.

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- *Inactivated vaccines*: Inactivated vaccines contain dead micro-organisms. They produce an immunity that is shorter lasting than immunisation using live attenuated micro-organisms. Examples of vaccines of this type include cholera, typhoid and whooping cough vaccines.
- *Toxoid vaccines*: In cases where bacteria produce their effects in humans by liberating toxins, it is not necessary to use the bacteria for immunisation. The toxins produced by the bacteria can be inactivated, so that when they are injected into someone they do not make the person ill. Such inactivated toxins are called **toxoids**. Injections of toxoids are used to immunise against diphtheria and tetanus.
- *Sub-unit vaccine*: Instead of using a whole dead or attenuated micro-organism, a fragment of the organism can be used to provoke the immune response. Sub-unit vaccines are used for vaccination against human papilloma virus (Gardasil) and hepatitis B.

Pasteur
This website provides more information on the work of Louis Pasteur and the discovery of vaccines.

Scientists are constantly investigating alternative methods of immunisation that are more effective with fewer side effects. One approach is to modify the characteristics of the pathogen by slightly changing the DNA in the micro-organism's cell, making the pathogen less virulent. Another method is to insert certain DNA sequences from the pathogen into harmless bacterial cells. The chosen DNA sequence causes the production of antigens that are characteristic of the pathogen. Vaccination with the harmless bacterium results in immunity against the pathogen. It is likely that a great many future vaccines will be made using this **recombinant DNA** method. Recombinant DNA will be discussed further in Chapter 8.

Vaccine delivery

The most common method of vaccination is to inject the vaccine using a syringe, but other forms of delivery can be used. One type of polio vaccine is given by mouth in a sweet syrup or in lumps of sugar. This method is no longer used in Australia but is still in use in many countries. Other forms of delivery are currently under research, including a fine spray, skin patches and ingestion in food.

Dreamstime.com/Paulus Rusyanto

FIGURE 7.27 Childhood vaccinations greatly reduce certain illnesses in children and also prevent the spread of communicable disease

Vaccination schedule

Most vaccinations do not start until a child is two months old, and for most diseases more than one vaccination is necessary.

Vaccination should not start too soon after birth, as the child's blood contains antibodies from its mother via the placenta or in breast milk. If a newborn is given a vaccine, the antibodies from the mother eliminate the antigens in the vaccine. This occurs before the child's immune system can mount an immune response. A few months are also necessary for the child's immune system to become activated and therefore able to prevent the child from getting the diseases that they are being vaccinated against. The hepatitis B vaccine is an exception to this, due to the risk of the infant being infected during birth. Therefore, the first vaccine is given soon after birth to provide early protection for the baby.

Unfortunately, one injection of a vaccine is not usually enough to protect a person from the particular disease they are being vaccinated against. The antibody levels from the primary response following the first vaccination will decline. Therefore, a second vaccination, called a booster, is needed stimulate a secondary response. The memory cells react quickly to this second exposure, resulting in a higher, longer-lasting level of antibodies in addition to more memory cells.

The timing of a booster shot is important. If the booster is given too soon after the first vaccination, the antibodies present in the blood will eliminate the material in the vaccine before more B-cells can be activated. To avoid this, a period of time between vaccinations is required, to allow the antibodies in the blood to be eliminated. Usually, this takes around two months.

In Australia, most people are vaccinated against the diseases for which vaccines are available. Table 7.5 shows a recommended vaccination schedule for Australians from birth through to adult life. For Australians travelling overseas, other vaccinations such as cholera, yellow fever and typhoid may be recommended, depending on the destination.

Key concept

Vaccines work by stimulating the immune system to promote immunity for an antigen. More than one vaccination is often needed to develop sufficient levels of antibodies and memory cells to protect the individual.

TABLE 7.5 Recommended vaccination schedule for Australians

AGE	RECOMMENDED VACCINATION
Birth	Hepatitis B
2 and 4 months	Diphtheria, tetanus, whooping cough; polio; hepatitis B; *Haemophilus influenzae* type B (HiB); rotavirus*; pneumococcal**
6 months	Diphtheria, tetanus, whooping cough, polio, HiB, rotavirus, pneumococcal, hepatitis B
12 months	Measles, mumps, rubella (MMR), HiB, meningococcal C***
18 months	Measles, mumps, rubella, chickenpox
4 years	Diphtheria, tetanus, whooping cough, polio, measles, mumps, rubella (MMR only if not given at 18 months)
10–15 years	Hepatitis B, chickenpox, diphtheria, tetanus, whooping cough, human papillomavirus (HPV)
15 years and over	Influenza (for Aboriginal and Torres Strait Islander people), pneumococcal (for Aboriginal and Torres Strait Islander people medically at risk)
50 years and over	Influenza (for Aboriginal and Torres Strait Islander people), pneumococcal (for Aboriginal and Torres Strait Islander people)
Pregnant women	Influenza
65 years and over	Influenza (annually), pneumococcal

Source: NHMRC Australian Standard Vaccination Schedule, 1 July 2013.

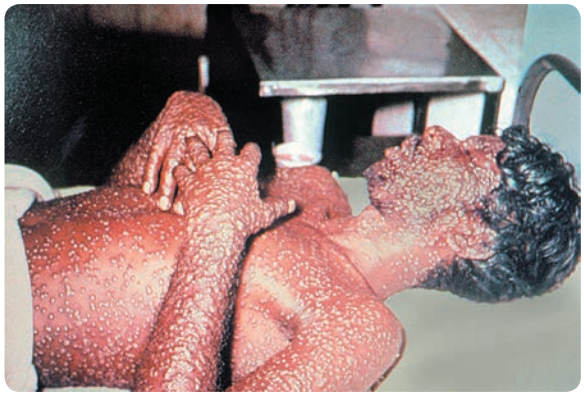
Notes: *Protects against a highly infectious disease of the small intestine; most cases occur in children under five years.

**Protects against a bacterial infection of the lung that may lead to pneumonia if it occurs in children or the elderly.

***Protects against a bacterial infection of the membranes around the brain.

Vaccination of populations

The World Health Organization (WHO) rates the introduction of vaccines as one of the public health measures that has had the greatest impact on people's health. The use of vaccines in mass immunisation programs has either eradicated or greatly reduced the incidence of certain diseases throughout the world. WHO's greatest success is probably the global elimination of smallpox. The last known naturally occurring case was in Somalia in 1977, although a small number of laboratory-acquired infections have occurred since then. The WHO is now determined to eliminate polio using a range of vaccination programs. Since 1988, the number of polio cases globally has decreased from about 350 000 a year to 22 cases in 2017.



Alamy Stock Photo/Science History Images

FIGURE 7.28 Smallpox causes a rash with raised pustules filled with pus-like fluid

Other vaccination programs are on a smaller scale and are frequently used to prevent the possibility of a serious outbreak of a highly infectious disease. In Australia, prior to winter each year, the federal government supports a program to vaccinate the young and the elderly against current strains of the influenza virus. Such vaccination programs not only reduce the chance of disease in the most susceptible individuals but also increase the immunity of the population. Such immunity is referred to as **herd immunity** and depends on a high proportion of individuals being immunised. When there are a large number of immune individuals in a population, there is less chance of the disease being transmitted between them.

The proportion of the population that needs to be immune to protect the population varies between diseases. Highly contagious diseases, such as measles, need a very high percentage of the population to be vaccinated to provide protection. However, a smaller percentage is needed for protection from less contagious diseases, such as Ebola.

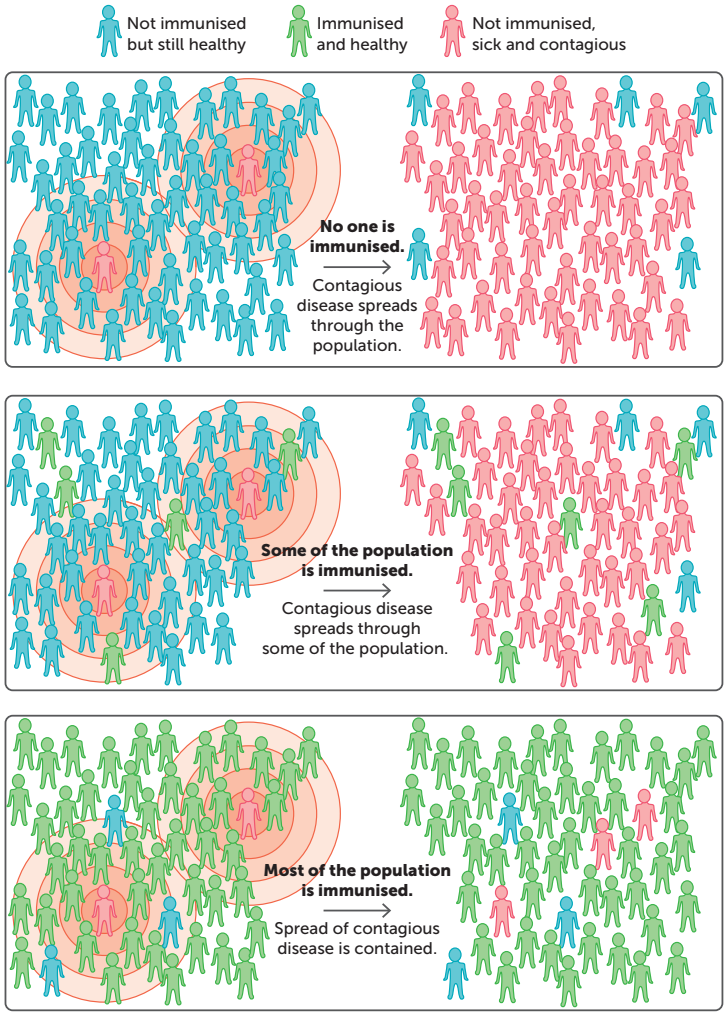


FIGURE 7.29 Herd immunity protects the whole population

Herd immunity
This website contains more information about herd immunity

Herd immunity simulation
This website has a simulation comparing the spread of disease in communities with different levels of immunisation.

One problem for health departments in all countries is that, as the incidence of infectious diseases declines, people become complacent and may decide that the risk of side effects from the vaccine is higher than the risk of contracting the disease itself. If vaccination rates do decline, a serious outbreak of a disease may occur. This happened in the United Kingdom in the 1970s, resulting in large outbreaks of whooping cough. Even in countries where vaccination rates are high, vaccine-preventable diseases have sometimes reappeared. The Netherlands, for example, has one of the highest rates of fully vaccinated people in the world. Nevertheless, there are groups of Dutch people who object to vaccination on religious grounds. In the early 1990s, a large outbreak of polio affected these people, with some suffering severe complications such as paralysis. However, polio did not spread into the rest of the Dutch community because of the protection provided by the high rates of vaccination.

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Key concept

Herd immunity relies on a large proportion of the population being immune to a disease to protect the whole population.

Factors to consider with vaccinations

One of the important choices that parents must make is whether to have their children vaccinated in infancy. Childhood vaccination is not compulsory in Australia, but in 2019 the Australian Government Department of Health reported that 94.31% of infants had been vaccinated by the age of 12 months.

There are many reasons to get vaccinated. Vaccinations provide protection for both individuals and whole populations. Negative side effects, while possible, are rare. Additionally, there are often reduced costs for things like health care, and in some states, such as Western Australia, it is a requirement of enrolment in a child-care or educational establishment.

As with all medical procedures, there are risks involved in the use of vaccines. However, there are strict guidelines that aim to minimise the possible risks. Before vaccines are made available for general use, they are tested for safety and effectiveness, first in clinical trials and then in much larger trials. In Australia, all vaccines on the market are manufactured according to strict safety guidelines. Before marketing approval is granted, they are evaluated by the Therapeutic Goods Administration to ensure they are effective and are at a high standard of quality and safety.

In Australian society, the Internet and other media are major sources of misinformation about the risks and benefits of immunisation. In 2014, the NSW Healthcare Complaints Commission ordered an anti-vaccination website to change its name, and a warning was issued about the unreliability of information published on that site. When accessing the Internet for material about immunisation, it is essential to check the reliability of the sources.

Various factors may affect a person's viewpoint on vaccines.

Inability to be vaccinated due to health issues

- *Allergic reactions*: One of the main risks of vaccination is an allergic reaction. This may occur, not so much from the vaccine itself, but from a reaction to the medium in which the vaccine was cultured. The National Health and Medical Research Council lists the possible vaccine components that may result in an allergic response. For example, many of the influenza vaccines are manufactured in fertilised eggs, and people who are allergic to egg protein need to be aware of this. Similarly, people who are allergic to yeast would need to be mindful that some of the older hepatitis B vaccines have yeast as a component.
- *Preservatives*: In the manufacture of vaccines, certain chemicals are used as preservatives. Preservatives used include thiomersal, formaldehyde, phenol (carbolic acid), aluminium phosphate, alum and acetone. Individuals concerned about vaccination claim that these preservatives can affect the nervous system and lead to other health issues. Such claims have been investigated on a number of occasions, and no connection has been identified. Instead, it appears that any reaction is due to chance alone.

Vaccination safety
This article from the *Medical Journal of Australia* discusses the risks associated with vaccines.

Social factors

- *Ethical concerns with the use of animals to produce vaccines*: As viruses can only reproduce in living cells, the manufacture of viral vaccines requires host tissue. For example, influenza virus is cultured in chicken embryos and Japanese encephalitis virus is grown in the brains of mice. Consequently, some people are concerned about the treatment of animals in the production of vaccines.
- *Ethical concerns with the use of human tissue to produce vaccines*: Many vaccines require human tissue because some viruses that cause disease in humans do not grow well in cells derived from other species. In addition, the use of human tissue avoids the problems of cross-species infection from possible unknown viruses. The source of the human tissue is a concern for many people. For example, rubella vaccine is manufactured using cultured human

cells. The original cells for the cultures were obtained from human foetuses. This raises moral questions for people who are opposed to the way in which those original cells were obtained.

- *Ethical concerns with informed consent*: A key principle of ethics is informed consent, and this applies to trialling vaccines. There is some concern that trailling vaccines in developing countries may lead to their use in populations with low standards of education. This may mean that people are not fully aware of the risks and may be open to exploitation by the vaccine's manufacturer.
- *Ethical concerns with testing on animals*: Before clinical trials on humans, most vaccines are tested on animals to identify problems that could arise in humans. The animals used in such testing are frequently mice, but other mammals are also used, along with birds, amphibians and fish. Legislation exists to limit the way that animals can be used; however, some people do not believe they should be used at all.
- *Concerns about promoting sexual activity in teenagers*: Some people believe that vaccinating against the sexually transmitted infection human papilloma virus will likely encourage teenagers to be sexually active.
- *Availability*: Vaccines may not be readily available in all areas.

Cultural factors

- *Religious beliefs*: Religious belief has often been cited as a reason for some Australian parents refusing to immunise their children. However, none of the major religions in Australia – Christianity, Islam and Judaism – are opposed to immunisation. There are, however, a few religions that are opposed to vaccines. These are religions that rely on faith healing or healing through prayer, such as Church of the First Born and First Church of Christ. In addition, the methods used to produce vaccines may contradict religious beliefs and lead to a choice not to participate in immunisation programs.

Religion and vaccines
This article discusses the religions that are opposed to vaccines.

Economic factors

- *Cost of vaccine*: The vaccines may be too expensive for some people to afford.
- *Commercialisation*: The interests of commercial vaccine production may affect its use.

In all issues relating to vaccines, individuals must be guided by their own beliefs and values. However, before making a decision about vaccination, it is the responsibility of each of us to ensure we are fully informed about all the possible consequences of the decision.

7.2 Specific resistance to infection

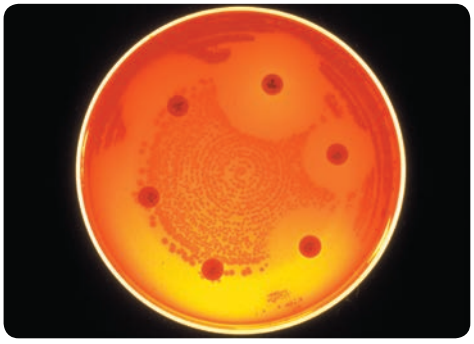
Activity 7.4
Investigating the testing of animals in the manufacture of vaccines

Key concept

The decision to participate in immunisation programs should be made after careful consideration of the risks and benefits, as well as any social, cultural or economic considerations.

Antibiotics

Antibiotics are drugs that are used to fight infections of micro-organisms, particularly bacteria. They cannot be used to treat viral infections. Each antibiotic is effective for only certain types of bacterial infection, and testing is often carried out prior to antibiotics being prescribed.



Medical Images RM/Bob Tapper

FIGURE 7.30
Comparing antibiotic sensitivity of bacteria using a culture plate with antibiotic assay discs. The discs surrounded by a clear area contain antibiotics that are effective for this type of bacteria

Before antibiotics came to be widely used in the 1940s, a person could die from an infected cut or scratch that today would be considered a minor problem. The discovery of antibiotics brought about a revolution in the treatment of bacterial infections, and they are now one of the most frequently prescribed drugs.

The first antibiotic to be identified was penicillin, when it was discovered that the mould *Penicillium notatum* was able to stop the growth of the *Staphylococcus* bacteria. Penicillin works by preventing the synthesis of the walls of the bacterial cells, inhibiting the reproduction of bacteria. About 30% of antibiotics used in Australia today are penicillin based, including amoxicillin and ampicillin. However, the effectiveness of penicillin has been reduced because many bacteria have developed resistance to it. Also, about 10% of people are allergic to penicillin.

Since the discovery of penicillin, a number of different antibiotics have also been developed, including:

- Streptomycin, erythromycin, neomycin, tetracycline and vancomycin, which interfere with protein synthesis in the cells of the target bacteria.
- Cephalosporin, which interferes with synthesis of the cell wall. It is much less likely than penicillin to produce allergic reactions.

There are two types of antibiotics. **Bactericidal antibiotics** kill bacteria by changing the structure of the cell wall or cell membrane, or by disrupting the action of essential enzymes. **Bacteriostatic antibiotics** stop bacteria from reproducing, usually by disrupting protein synthesis. Both types are effective in treating bacterial infections.

Some antibiotics affect a wide range of different types of bacteria. These are **broad-spectrum antibiotics**. Others, **narrow-spectrum antibiotics**, are effective only against specific types of bacteria.

The widespread use of antibiotics has created a major problem. Some of the bacteria that antibiotics are used to kill have gradually evolved and become resistant to them. In the early days of antibiotic use, the problem was easily solved by changing to a different antibiotic. However, some strains of bacteria are now resistant to most or all available types of antibiotics. This is known as **multiple drug resistance** and such bacteria are often referred to as 'super bugs'. In 2012 it was reported that 12 cases of tuberculosis in Mumbai, India, were resistant to all known drugs; that is, they showed **total drug resistance**. Totally resistant strains of the bacterium that causes gonorrhoea have been detected in Australia, Japan and Europe.

Multiple drug resistance has been hastened by the overuse of antibiotics in medicine and in agriculture. Doctors have prescribed antibiotics to prevent infection rather than to treat an existing infection. Farmers use antibiotics as 'growth promoters' in poultry, pigs and cattle. International efforts are now being made to reduce the use of antibiotics so that the development of further strains of multiple drug-resistant bacteria will be delayed.

Prevention of misuse and abuse of antibiotics will slow the development of resistance, but there is no way of stopping it altogether. Strategies being used to overcome the problem are to develop new classes of antibiotics to which bacteria have no resistance, to revive old antibiotics by using them in combination with other substances, and to genetically engineer bacteria to disable antibiotic-resistant genes.

Discovery and development of penicillin
This website looks at the discovery of penicillin.

Antibiotics
This website provides information on how antibiotics work.

Activity 7.5
Investigating antibiotic resistance

Antivirals

Antiviral drugs are used specifically for treating viral infections. Because antibiotics are ineffective against viruses, there is still no treatment for common ailments such as colds, chickenpox and measles. This has led to a hunt for chemicals that can be used as antivirals.

Viruses enter a host cell, and the virus DNA or RNA induces the cell to produce new virus particles. These particles can then leave the cell and infect new host cells. The way in which viruses replicate makes it difficult to find drugs that will treat viral infections. Because the host cell produces the new virus particles, any drug that interferes with virus replication is likely to be toxic to the host.

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Early research involved culturing cells, infecting them with a virus and then trying different chemicals to see whether the amount of virus decreased. This time-consuming and hit-or-miss technique produced little result.

In the 1980s, it became possible to determine the genetic sequences of viruses so that scientists could find out exactly how they work. Research today is aimed at identifying viral proteins that can be disabled by specially designed chemicals. If the proteins are very different from human proteins, there should be few side effects from the use of such drugs.

Unlike most of the antibiotics that destroy pathogenic bacteria, antivirals inhibit the development of the virus. Most of the antiviral drugs that are now available target HIV, herpes, hepatitis B and C, and influenza A and B.

Some examples of antivirals that you may have heard of are Tamiflu and Relenza for influenza, acyclovir (marketed as Zovirax) for herpes infections, interferons for hepatitis B and C, and zidovudine (AZT) for human immunodeficiency virus. A great deal of research is being carried out to develop drugs that will target other viruses such as coronavirus.

Key concept

Antibiotics are used to treat bacterial infections, and antiviral drugs are used to treat viral infections.

Questions 7.4

RECALL KNOWLEDGE

1. Define 'vaccination'.
2. List the ways that vaccines have traditionally been made.
3. Why are infants not vaccinated against most diseases until at least two months of age?
4. Define 'herd immunity' and describe what is needed to achieve it.
5. List some of the reasons that people may choose not to be vaccinated.
6. Penicillin is an antibiotic.
   - a Define 'antibiotic'.
   - b List two other antibiotics.
   - c Would penicillin be effective in treating an infection caused by the influenza virus? Explain.
7. Define 'antiviral drug' and identify an infection that is able to be treated with antiviral drugs.

APPLY KNOWLEDGE

8. A person whose immune system is compromised is unable to be vaccinated. Explain why this is so, and why herd immunity plays a vital role in this person's health.
9. Explain how it is possible to introduce a virus or bacteria in a vaccine without producing the associated disease.
10. Which antibiotic is more important – broad-spectrum or narrow-spectrum? Justify your answer.
11. 'Golden staph' is a common name for the bacteria *Staphylococcus aureus* that can be resistant to most commonly used antibiotics. Explain why this bacteria is such a problem.
12. Explain why antiviral drugs are harder to develop than antibiotics.
13. Use a table to compare and contrast bacteria and viruses in terms of:
    - a their size
    - b their structure
    - c whether they are living or non-living
    - d how they replicate
    - e how they affect the body
    - f treatment.

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CHAPTER 7 ACTIVITIES

ACTIVITY 7.1 Investigating the effectiveness of hand washing

Hand washing is recommended as a way of reducing the spread of bacteria. Antiseptics are used to further reduce the risk of infection.

The purpose of this activity is to compare the effectiveness of different methods of hand washing or types of soap.

The presence of bacteria on the skin of the fingers can be demonstrated by pressing the fingers on to the surface of the medium in a sterile culture plate, a petri dish with a thin layer of agar jelly in the bottom. After pressing the fingers on to the agar, the plate is incubated (kept in a warm place) for several days. Bacteria that were transferred from the fingers to the agar will reproduce and form colonies that can be seen with the naked eye. The more colonies, the more bacteria there were on the skin.

You will need

For each pair or group: six or more sterile nutrient agar plates; two large beakers; soap or soap solution; antiseptic solution such as Dettol, Solyptol or Cetavlon; marking pen; adhesive tape; an incubator (if available)

Planning your investigation

1. What will be your independent variable? You may wish to test different types of soap, different methods of hand washing, different lengths of time of hand washing, antiseptic solution vs antiseptic wipes, natural soaps vs synthetic soaps, or another factor.
2. What will be your dependent variable?
3. What variables will you need to control? How will you do this?
4. Draw up a suitable table in which to record your results.

Risk assessment

Bacteria can be dangerous and cause disease. Therefore, the lids on the plates should never be removed after they have been exposed. Plates should be autoclaved and disposed of following the investigation.

What to do

Follow the steps below for each of your tests.

1. Do not open the lid of the sterile culture plate until you are ready to press your fingers on to the surface. It is most important that exposure of the plates to the atmosphere be kept to an absolute minimum.
2. Press gently on the surface; do not push your fingers into the agar.
3. Replace the lid on the culture plate as quickly as possible.
4. Label the plate.
5. Tape the lid on to the plate with two pieces of adhesive tape so that it cannot be accidentally removed.
6. **Never remove the lid after the plate has been exposed.**
7. Incubate the plates upside down so that any moisture condensing on the lid of the plate cannot drip on to the nutrient medium.
8. At the end of the incubation period, count the number of bacterial colonies that have grown on the agar or calculate the area of the plate covered. You could also count the number of different species of bacteria. (Each one will have a different colour or texture.)
9. Autoclave the plates at 120°C for 20 minutes under 100 kPa pressure to make sure that any micro-organisms are destroyed.
10. Dispose of the plates with the lid still in place.

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Studying your results

Discuss the results of your investigation. Your discussion should include answers to the following questions.

1. Was your hypothesis supported or disproved?
2. What were some sources of error in your investigation? Did these affect its accuracy, reliability or validity?
3. How confident are you of your results? Why is this so?
4. What further investigations need to be made?
5. What improvement could be made to your experimental procedure?

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ACTIVITY 7.2 Investigating infectious disease transmission

An infectious disease is a pathogen that is passed from one host to another. These diseases can spread in several ways, including direct contact with an infected individual, indirect contact via surfaces or objects touched by an infected individual, and airborne droplets that result from infected individuals sneezing, coughing or laughing. The transmission of disease through these droplets depends on how close the infected individual and potential host are, as the droplets disperse and settle quickly. The common cold and influenza are typically transmitted through droplets in the air. Local health departments, the World Health Organization (WHO) and the Centres for Disease Control and Prevention (CDC) are responsible for monitoring infectious disease outbreaks. These agencies are responsible for identifying the source of outbreaks by tracking the routes of transmission. Over the past 100 years, these organisations, along with vaccine development and sanitation improvement, have effectively fought the spread of disease. Many of the infectious diseases that have historically been responsible for devastating epidemics have now been reduced or even eradicated.

Aim

To simulate a real-case scenario infectious disease transmission and identify patient zero
Time requirement: 45 minutes

You will need

1 screw-cap vial with solution (containing either 7 mL 0.001M hydrochloric acid or 7 mL 1M sodium hydroxide); phenol red indicator vial 15 mL; 1 plastic pipette; 4 96-well plates; marker; 1 index card; disposable gloves

Risks

WHAT ARE THE RISKS IN THIS INVESTIGATION?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Sodium hydroxide can cause severe skin burns and eye damage.	Ensure that appropriate PPE is worn at all times.
Disposable gloves may pose allergy risk.	Use a type of glove that removes allergy risk and is suitable for the chemicals being used.

What to do

1. Collect an index card, plastic pipette and a screw-cap vial containing solution. The solution in the vial represents bodily fluid. Your vial will be labelled with a number.
2. There are four well plates labelled 0, 1, 2 and 3. Locate your individual wells on the class well plates. These will be labelled with the number corresponding with the number on your vial.
3. Using a plastic pipette, remove some of the fluid from your vial and transfer five drops into your well on Well Plate 0.

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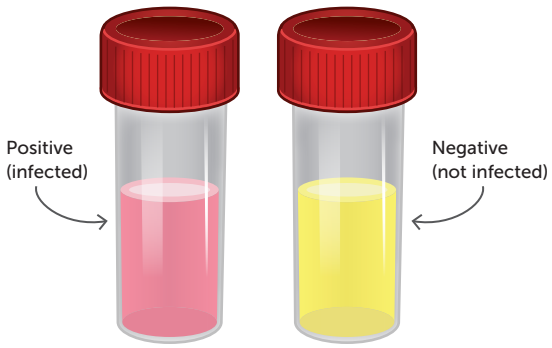
4 Select a partner, and record their name and vial number on your index card.
5 Using your plastic pipette, transfer five drops from your vial to your partner's vial. Return any liquid remaining in your pipette to your vial. Replace the vial cap and mix the solution by inverting it several times.
6 Using a plastic pipette, transfer five drops of liquid from your vial into your well on Well Plate 1.
7 Repeat steps 4 and 5 for the second and third exchanges, depositing your liquid into wells on Plates 2 and 3, respectively. Select a different partner for each round and complete each step before proceeding to the next exchange.
8 After all exchanges have been made, your teacher will add one drop of phenol red, an indicator solution that will determine if your vial has become 'infected'. Vials that turn red or pink are positive for the pathogen (infection), while vials that turn yellow are negative, indicating that your vial did not become infected.



9 Report if your vial tested positive. If so, share the names of the partners with whom you exchanged fluids.
10 Based on your individual results and the data from your classmates, try to identify which vial the infection spread from. Your teacher will add a drop of phenol red to each of the wells in the well plates. By observing which samples indicate a positive result in each round of transfers, you may be able to trace the spread of infection to the original source.
11 Copy and complete the table below to help you identify the source of infection. Once you have listed the positive vials and who they exchanged with, circle the numbers of the partners whose vials tested positive.

POSITIVE VIAL NUMBERS	1ST EXCHANGE PARTNER NUMBER	2ND EXCHANGE PARTNER NUMBER	3RD EXCHANGE PARTNER NUMBER

Studying your results

1 Who was patient zero?
2 After the three rounds of exchanges, how many vials tested positive? Calculate what percentage of your class this represents.
3 Graph how many students were infected after each round.

Discussion

1. If the class were divided into three groups of 10 at the start of this procedure and allowed to exchange only within their group, what would the transmission of the disease look like?
2. Did you know which vials were infected during the procedure?
3. Do you believe that an individual who does not show any signs of a disease can transmit it to others?
4. What is the importance of identifying patient zero in epidemics?
5. How does this simulation differ from the spread of disease in the real world, such as the spread of COVID-19? Explain.
6. List the appropriate measures that individuals should take to limit the spread of diseases.

Taking it further

Research past infectious disease epidemics. Your research should include:

- origins of the disease
- how the disease is transmitted
- typical incubation period
- symptoms/signs of the disease
- impact (i.e. death toll, cultural shifts, historical context)
- possible vaccines and treatments
- preventative measures.

ACTIVITY 7.3 Plotting a fever

Fever is when a person's body temperature is higher than the normal 37°C. It can result from injury, infection, toxins, reaction to a drug, or a number of other causes. At one time, it was thought that fever was harmful to the body and that everything possible should be done to reduce a high temperature. It is now known that, provided a person's temperature is not too high (over 40°C), fever can actually speed recovery.

The table shows the temperature recorded for a person who suffered a viral infection and recovered after about 10 days.

DAY	TIME	BODY TEMPERATURE (°C)
1	8 a.m.	37.1
	8 p.m.	37.4
2	8 a.m.	37.2
	8 p.m.	38.1
3	8 a.m.	38.6
	8 p.m.	39.2
4	8 a.m.	39.1
	8 p.m.	38.9
5	8 a.m.	39.2
	8 p.m.	39.3
6	8 a.m.	38.8
	8 p.m.	39.0
7	8 a.m.	39.1
	8 p.m.	38.7
8	8 a.m.	38.3
	8 p.m.	38.1
9	8 a.m.	37.7
	8 p.m.	37.4
10	8 a.m.	37.2
	8 p.m.	36.9
11	8 a.m.	37.1
	8 p.m.	37.2

What to do

1. Plot the data on a graph. Refer to Chapter 1 to review how to draw a graph correctly.
2. Describe what happened to the patient's temperature over the 11-day period covered by the data.
3. Calculate the patient's average temperature from 8 a.m. on day 3 to 8 p.m. on day 8.
4. During a fever, the body's 'thermostat' is set to a higher level. Explain how your graph illustrates this characteristic of a fever.

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ACTIVITY 7.4 Investigating the testing of animals in the manufacture of vaccines

Hold a class discussion on the scientific and ethical issues arising from the use of animals in the research and manufacture of vaccines. Assign the roles of interested parties to some of the members of the class, who will then assume that role in the discussion. The roles could include:

- a person suffering from a disease for which researchers are trying to develop a vaccine
- a spokesperson for an animal rights group
- a doctor specialising in immunology
- a member of the public opposed to the activities of animal rights groups
- an employee of the health department responsible for control of infectious diseases
- a scientist researching new vaccines
- a person opposed to the use of vaccines because of the risks involved.

As well as moral and ethical issues, the discussion could consider questions such as these.

1. Why do people's opinions differ about what activities should be allowed in the development and manufacture of vaccines?
2. How can society best consider the wide range of views that people hold on these issues?
3. Who should be allowed to decide whether testing on animals should be permitted?
4. What are the responsibilities of the scientists who use animals for their testing programs?
5. Who should set standards for laboratories and researchers that use animals for the manufacture and testing of vaccines?

After listening to the opinions expressed during the discussions, prepare a list of arguments for and against the use of animals for the manufacture and testing of vaccines.

ACTIVITY 7.5 Investigating antibiotic resistance

Antibiotics are molecules that are produced by bacteria and fungi as a defence against other microbes. Penicillin was a revolutionary discovery for the human race in the 20th century. Along with other antibiotic discoveries, penicillin suddenly became a weapon against an invisible enemy. Antibiotics have been harnessed by scientists and medical professionals to treat diseases and save lives. Since that first discovery of antibiotics, they have been developed for use against the broad range of pathogenic microbes, each with their strengths and weaknesses. Unfortunately, this weapon has become dulled in the past decade as overuse has led to antibiotic resistance. Antibiotic resistance results from certain bacteria evolving to become resistant to the antibiotics that have been used to fight them. As a result, antibiotic medicines are not able to fight certain bacteria as effectively, and medical professionals have been forced to find alternative solutions. Not all antibiotics work against all bacteria, and knowing which bacteria are susceptible is essential to finding the best treatment for disease.

Aim

To investigate antibiotic effectiveness against common bacteria strains
Time requirement: 45 minutes

You will need

Escherichia coli broth culture; *Staphylococcus epidermidis* broth culture; 4 nutrient agar plates; 2 sterile pipettes; 2 disposable spreaders; 2 Mastring antibiotic discs; measuring ruler or callipers; sticky tape; marker; ethanol or bleach; sterile forceps; incubator; Bunsen burner; contaminated waste bag; disposable gloves

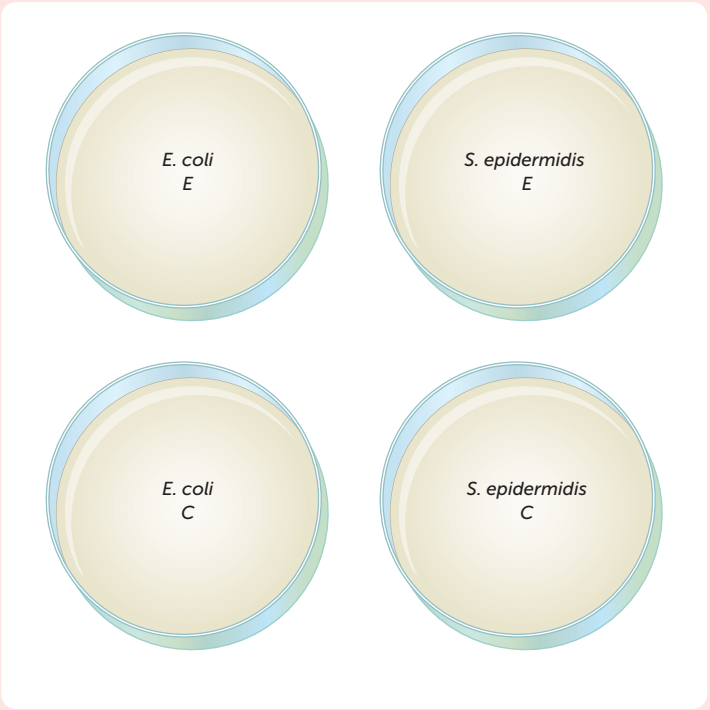
Risks

WHAT ARE THE RISKS IN THIS INVESTIGATION?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
While lab strains are usually harmless, bacteria may cause disease, so assume them to be pathogenic.	Wear lab coats, safety glasses and gloves; wash hands thoroughly at end. Decontaminate benches before and after activity. Flood spills with bleach.
Micro-organisms will grow on the agar plates.	Do not open plates once they are securely taped. Dispose of plates appropriately after autoclaving.
Disposable gloves may pose allergy risk.	Use a type of glove that removes allergy risk and is suitable for the chemicals being used.

What to do

Note: To use aseptic technique, wipe your bench down with ethanol (or bleach) and keep your work near the Bunsen burner to take advantage of the updraught the flame will create to waft potential contaminants away from your materials.

1 Label the bottom of your four agar plates with your name and the date. Label two plates *E. coli* and two plates *S. epidermidis*. Label one plate of each type of bacteria with 'E' for experiment and label the other 'C' for control.



2 Using a sterile plastic pipette, transfer one drop of the *E. coli* bacterial broth on to the surface of the agar on your two *E. coli* plates.
3 Working close to the Bunsen burner, use a spreader to spread the bacterial broth over the plates evenly. If you are using a glass spreader, pass it through the flame of the Bunsen burner before each use.
4 Replace the lids on the plates immediately to avoid contamination.
5 Repeat steps 2 to 4 for *S. epidermidis*, using a new sterile plastic pipette and spreader.

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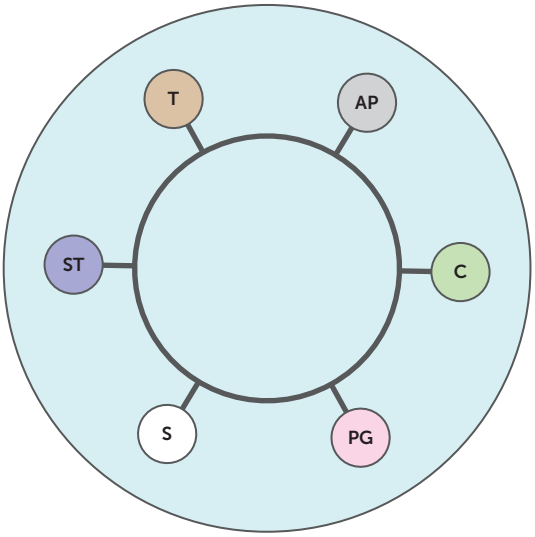
6 The next step is to apply the Mastring to each of the experiment plates. Wait 10–15 minutes before applying the Mastring to ensure that bacteria have a chance to grow.

7 To apply the Mastring, flame your forceps and allow them to cool before picking it up. Place it in the middle of your plate and push (very gently) with the forceps to help it stay in place. Each lobe of the Mastring is impregnated with a different antibiotic; use the code below or the one on the packet to differentiate them.



The symbols indicate antibiotics as follows:

- **AP** – AMPICILLIN (grey)
- **S** – STREPTOMYCIN (white)
- **C** – CHLORAMPHENICOL (green)
- **ST** – SULPHATRIAD (mauve)
- **PG** – PENICILLIN G (pink)
- **T** – TETRACYLINE (brown)

8 Repeat steps 6 and 7 for the other experiment plate, flaming the forceps between each application.

9 Seal all four plates with sticky tape and incubate for 24 hours at 37°C, upside down so that the agar is at the top.

10 Wipe your bench down with ethanol and clean your hands thoroughly.

11 Dispose of all materials safely in a contaminated-waste bag.

12 The next day, observe for the presence or absence of growth near the disc and measure the diameter of any zones of inhibition. Record your results and contribute to the class data pool.

Studying your results

1 Draw a diagram of what you see on each plate. Include labels.

2 Copy and complete the table below with the results of your experiment.

ANTIBIOTIC	DIAMETER OF ZONE OF INHIBITION (MM)	
	ESCHERICHIA COLI	*STAPHYLOCOCCUS EPIDERMIDIS*
Ampicillin		
Streptomycin		
Chloramphenicol		
Sulphatriad		
Penicillin		
Tetracycline		

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3 Calculate the class average diameter of the zone of inhibition for each antibiotic and copy and complete the table below with the results of your experiment.

ANTIBIOTIC	AVERAGE DIAMETER OF ZONE OF INHIBITION (MM)	
	ESCHERICHIA COLI	*STAPHYLOCOCCUS EPIDERMIDIS*
Ampicillin		
Streptomycin		
Chloramphenicol		
Sulphatriad		
Penicillin		
Tetracycline		

Discussion

1 Explain the function of the control plate in the experiment. How could a control plate be helpful in the event there is no growth on the experiment plate?
2 What were four variables that you kept constant in this experiment? How did you control them?
3 Why is it important to pool data from the class results and find the average zone of inhibition for each antibiotic?
4 What is a zone of inhibition? How were they created in your experiment?
5 Which antibiotic had the greatest zone of inhibition? Explain why this might be.
6 Did your individual results differ from the class results? If so, suggest possible reasons.
7 Which antibiotic would be most suitable to treat an infection by *Staphylococcus epidermidis*?
8 Which antibiotic would you use if you were unsure of the pathogen in an infection? Explain your answer.
9 Did your results show any signs of antibiotic resistance?
10 Discuss the effects that antibiotic resistance has on medical treatment.
11 Why have antibiotics become a less effective treatment for infection in recent years?

Taking it further

Test the efficacy of natural antibiotics on similar bacteria.

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CHAPTER 7 SUMMARY

- A pathogen is a disease-causing microorganism such as a bacterium or virus.
- A communicable, or infectious, disease can be transmitted from person to person.
- Bacteria are single-celled organisms that usually have a cell wall but not an organised nucleus or membrane-bound organelles. Most bacteria are harmless, or even beneficial. However, some are pathogens. Bacteria are classified by their shape and can be identified after growing on an agar plate of nutrient medium and then being viewed under a microscope.
- Viruses contain DNA or RNA within a protein coat. Some viruses also have an external envelope.
- Viruses cannot reproduce themselves. Instead, they infect a cell and use the cell to produce many copies of the virus, which are then released to infect more cells.
- Transmission of pathogens can occur by direct contact or ingestion, via body fluid, droplets or airborne particles, or through another animal called a vector.
- Non-specific defences, including external defences, protective reflexes, phagocytosis, inflammation, fever and the lymphatic system, are for all pathogens; while specific defences, including cell-mediated responses and antibody-mediated responses, are for one specific pathogen only.
- External defences stop a foreign particle entering the body. They include the skin, mucus, hairs and cilia, acid, lysozyme, cerumen and the movement of fluid.
- Protective reflexes are automatic responses to protect the body by eliminating the foreign particle or pathogen. They include sneezing, coughing, vomiting and diarrhoea.
- Phagocytosis involves a phagocyte engulfing and digesting the pathogen. Macrophages, neutrophils and dendritic cells are phagocytes.
- Inflammation occurs when tissue is damaged and causes heat, redness, swelling and pain. Mast cells release histamine, which increases blood flow to the damaged area and causes fluid to leak out of the vessels into the surrounding tissue. Heparin is also released and prevents the blood clotting. Phagocytes are attracted to the area and consume the pathogen, removing the cause of infection, allowing new cells to form and the tissue to heal.
- Pyrogens, such as Interleukin-1, can cause the set point for body temperature to increase. This means that homeostatic mechanisms will result in an increased body temperature. While this may help by inhibiting the growth of the pathogen, it is dangerous if it gets too high.
- The lymphatic system plays a role in non-specific responses, with lymph nodes filtering lymph and macrophages destroying pathogens.
- B-cells and T-cells are lymphocytes responsible for the body's specific defences by responding to antigens (large molecules that are capable of triggering an immune response).
- Antigen-presenting cells, such as dendritic cells and macrophages, engulf and digest the pathogen, then display the antigen on their surface to present to lymphocytes.
- The humoral response, or cell-mediated immunity, occurs when B-cells for a specific antigen are activated, forming a clone. Some of the clones become plasma cells, which produce antibodies; the rest become memory cells.
- Antibodies are specific to a particular antigen. They combine to form an antigen–antibody complex which can respond to pathogens by inactivating them, preventing them from entering cells, causing agglutination or increasing the chance of phagocytosis.

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- Memory cells remain in the body and are quick to respond to future exposures to the antigen.
- The first exposure to an antigen is the primary response. There is a delay before the level of antibodies is sufficient. Upon a second exposure, memory cells allow the body to respond much more quickly and produce greater levels of antibodies that last longer. This allows the body to remove the pathogen before it causes the disease.
- Cell-mediated immunity occurs when T-cells are activated by a B-cell or macrophage presenting the antigen to the T-cell. The T-cell enlarges, multiplies and produces a clone, which may become a killer T-cell or a helper T-cell. Killer T-cells inactivate the pathogen by releasing substances that destroy it. Helper T-cells act indirectly by causing an increase in phagocytosis. If the response is too great, suppressor T-cells are produced, which inhibit T-cell and B-cell activity. Memory cells are also produced, which remain in the body and respond quickly if the same pathogen enters the body again.
- Immunity may be natural or artificial.
- If immunity is due to receiving antibodies, without the body responding to an antigen, it is passive immunity – for example, a baby receiving antibodies in breast milk. If immunity is due to the body responding to antigens, it is active immunity – for example, being exposed to a pathogen.
- Vaccinations can lead to immunisation by artificially introducing pathogens and allowing the body to develop immunity. Vaccines do not cause the disease as the antigen is introduced without the active pathogen. For example, the pathogen may be inactivated (attenuated) or dead, or the vaccine may contain an inactivated toxin or only part of the pathogen.
- Recombinant DNA is being investigated to make vaccines by adding the DNA responsible for the antigen to harmless bacteria. This should allow safer, more effective vaccines to be developed.
- Booster shots of vaccines are often needed to utilise the secondary response to ensure that the levels of antibodies and memory cells are sufficient to protect the body from disease.
- If enough people in a population are immune to a disease, they can protect the rest of the population by making the spread of the disease less likely. This is herd immunity.
- There are many factors to consider in relation to vaccinations. These include allergic reactions, ethical concerns and religious beliefs.
- Antibiotics fight infections, particularly those due to bacteria, by destroying the cell wall or membrane, or stopping their reproduction.
- Some bacteria have evolved to become resistant to antibiotics. This evolution has been hastened by incorrect use of antibiotics.
- Antiviral drugs treat viral infections. They are harder to develop, as viruses invade the host cells. Therefore, killing a virus also affects its host cells.

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CHAPTER 7 GLOSSARY

Active immunity Immunity produced by the body manufacturing antibodies against a foreign antigen

Agglutination The clumping together of micro-organisms or cells

Antibiotic A chemical able to inhibit the growth of, or to kill, micro-organisms, particularly bacteria

Antibody A substance produced in response to a specific antigen; combines with the antigen to neutralise or destroy it

Antibody-mediated immunity *see* humoral response

Antigen Any substance capable of causing the formation of antibodies when introduced into the tissues

Antigen–antibody complex A compound formed when an antibody combines with an antigen

Antigen-presenting cells Phagocytic cells that digest pathogens and present the antigen to lymphocytes; include dendritic cells and macrophages

Antiviral drug A drug used for the treatment of viral infections

Artificial immunity Immunity produced by giving a person an antigen, which triggers the immune response, or by giving them antibodies to an infecting antigen

Attenuated Describes micro-organisms that have been reduced in virulence

Bacteria Unicellular, prokaryotic organisms with a cell wall but lacking membrane-bound organelles and an organised nucleus; singular: bacterium

Bactericidal antibiotic A drug used to treat bacterial infections by killing the bacteria

Bacteriophage A virus that infects bacteria

Bacteriostatic antibiotic A drug used to treat bacterial infections; it does not kill the bacteria but stops them reproducing

B-cell A type of lymphocyte that develops into either a plasma cell that produces antibodies or a memory cell

Broad-spectrum antibiotic An antibiotic that affects many types of bacteria

Cell-mediated response The part of the immune response in which T-cells attach to antigens to destroy them; also called cellular immunity

Cerumen Ear wax; secreted by special glands near the opening of the ear canal

Cilia Hair-like projections from a cell; they beat rhythmically to move material across a tissue surface; singular: cilium

Clone A group of cells with the same genetic characteristics

Communicable disease A disease passed from one person to another by infection with micro-organisms; also called an infectious or transmissible disease

Complement system A system of proteins produced by the liver that enhance the activity of antibodies and phagocytes

Contagious A disease passed on by direct human contact

Cytokines Small proteins that are released in response to antigens and act as messengers in the immune response

Cytotoxic T-cells *see* killer T-cell

Dendritic cell An antigen-presenting cell, named due to the branch-like extensions from the cytoplasm

Fever An elevation of body temperature above the normal level of 37°C

Helper T-cell A type of T-cell that, among other things, enhances antibody production by B-cells

Heparin A substance that helps to prevent blood clotting

Herd immunity A type of 'group' immunity that occurs when such a high proportion of people in a population are immunised that those who are not immune are protected

Histamine A substance released in response to injury to cells; it results in an increase in blood flow

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Humoral response A response triggered by foreign substances or micro-organisms entering the body, involving B-cells and the production of antibodies; also known as antibody-mediated immunity

Immune response A response triggered by foreign substances or micro-organisms entering the body

Immune system Different types of cells that occur in most organs of the body and that protect against foreign organisms, alien chemicals and abnormal cells

Immunisation Programming the immune system so that the body can respond rapidly to infecting micro-organisms

Immunity Resistance to infection from invading micro-organisms

Immunoglobulin A particular group of proteins; antibodies are immunoglobulins

Infectious disease *see* communicable disease

Inflammation The response to damage to a tissue; involves swelling, heat, pain and redness in the affected area

Interferon Any of several proteins that are produced by cells as a defensive response to viral infection, preventing the replication of the virus

Interleukin-1 A pyrogen produced primarily by macrophages

Killer T-cell A type of T-lymphocyte able to kill cells that are damaged or infected with viruses or bacteria; also called cytotoxic T-cell

Leucocyte A white blood cell; also spelt leukocyte

Lymphatic system A system of vessels that drain excess fluid from the tissues; also called the lymph system

Lymphocyte A white blood cell that is responsible for the immune response

Lymphoid tissue Tissue containing many lymphocytes and macrophages; found mostly in the lymph nodes but also in the bone marrow, tonsils, spleen and thymus

Lysozyme An enzyme that kills bacteria; found in tears, saliva and perspiration

Macrophage A phagocytic cell derived from a monocyte (a type of white blood cell)

Mast cell A type of cell found in loose connective tissue; involved in the inflammatory response

Memory cell A type of cell that recognises an antigen to which the body has previously been exposed

Monocyte A type of leucocyte found in the blood that migrates into damaged tissue and forms macrophages

Mucous membrane An epithelial tissue that secretes mucus and lines many body cavities

Mucus A slippery, stringy substance produced by mucous membranes

Multiple drug resistance Resistance of some strains of bacteria to most of the available antibiotics

Narrow-spectrum antibiotic An antibiotic that affects only a particular type of bacteria

Nasal cavity The large air-filled cavity above and behind the nose

Natural immunity Immunity that occurs without any human intervention

Neutrophil A granulated leucocyte with a multilobar nucleus that is phagocytotic

Non-self antigen Any compound foreign to the body that triggers an immune response

Non-specific defence Defence of the body that acts against all pathogens

Passive immunity Immunity produced by the introduction of antibodies from another person

Pathogen A disease-causing organism; often referred to as a pathogenic organism

Phagocyte Cells that are able to engulf micro-organisms and cell debris

Plasma cell A cell that develops from a B-cell and produces antibodies

Plasmid In a bacterial cell, small circular strands of DNA distinct from the main bacterial genome; composed of only a few genes and able to replicate independently within cells

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Primary response The response of the immune system to the first exposure to an antigen

Prokaryote A single-celled organism lacking a distinct nucleus or specialised organelles

Pyrogen A substance that results in a fever

Recombinant DNA Synthetic DNA; made by inserting genes from one source into a DNA molecule from a different source

Sebum An oily, waxy secretion from the sebaceous glands

Secondary response The response to a second or subsequent exposure to an antigen; the secondary response is faster and more intense than the primary response

Self-antigen Any large molecule produced in a person's own body; does not cause an immune response in that person

Specific defence Defence of the body that is directed against a specific pathogen

Suppressor T-cell A type of T-cell that helps to slow down the immune response

Sweat The liquid produced by the sweat glands on the skin

T-cell A lymphocyte that can differentiate into a number of different kinds of cell, all of which are involved in cell-mediated immunity

Total drug resistance The resistance of some strains of bacteria to all antibiotics

Toxoid A toxin from a pathogenic organism that is altered so that it is no longer toxic

Vaccination The introduction of antigens to a person so that they acquire immunity without suffering from the illness

Vaccine An antigen preparation used in artificial immunisation

Vasodilation An increase in the diameter of arterioles, increasing the flow of blood through them

Vector An agent such as an insect capable of transferring a disease-causing organism from one person to another

Virulence The disease-producing power of a micro-organism

Virus An infectious agent, too small to be seen with a light microscope, consisting of a protein sheath surrounding a core of nucleic acid; viruses are totally dependent on living cells for reproduction

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CHAPTER 7 REVIEW QUESTIONS

Recall

1 Define 'communicable disease' and name five examples.

2 List the external defences that prevent the entry of pathogenic organisms into the body.

3 a How do protective reflexes help to defend the body from infection by pathogenic organisms?
  b List four reflexes that help to protect against infection.

4 In the inflammatory response, describe the role of:
  a mast cells
  b histamine
  c heparin
  d phagocytes.

5 How is fever during the course of an infection thought to be beneficial?

6 Why is the immune response said to be a specific response?

7 a What is an antigen?
  b Explain the difference between self-antigens and non-self antigens.

8 List the ways in which the antigen–antibody complex helps to overcome the effects of invading micro-organisms.

9 List the ways in which killer T-cells and helper T-cells can deal with an invading antigen.

10 a How can passive immunity be gained artificially?
  b How can active immunity be acquired naturally?

11 a What is a vaccine?
  b Describe three ways in which older types of vaccines are produced.
  c What new methods are being trialled to produce vaccines?
  d List the risks associated with the use of vaccines.

12 Explain the difference between:
  a an antibiotic and an antiviral
  b a bactericidal and a bacteriostatic antibiotic
  c a broad-spectrum and a narrow-spectrum antibiotic.

Explain

13 Explain the difference between:
  a a pathogen and a vector
  b RNA viruses and DNA viruses
  c bacteria and bacteriophages.

14 Explain the importance of phagocytes in defence against disease.

15 Explain what causes the four signs of inflammation.

16 Explain the difference between:
  a natural and artificial immunity
  b active and passive immunity.

17 Why is the secondary immune response so much faster than the primary response?

18 Why is it rare to get a disease such as measles or chickenpox more than once?

19 Explain how T-cells are able to produce immunity.

Apply

20 a Bacteria were first detected in 1683, but viruses were not detected until 1938. Suggest why this happened.
  b List four differences between bacteria and viruses.

21 Explain how coughing into your elbow can help reduce the spread of disease.

22 Draw a flow chart showing the events that occur in an inflammatory response.

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23 Explain why someone with an infected toe may develop a lump in the groin.

24 During a fever, people often have severe chills and can shiver uncontrollably even though their temperature is above normal. Explain how this is thought to come about.

25 Compare and contrast antigens and antibodies.

26 Draw a flow chart to show how cell-mediated immunity is activated.

27 Typhoid is caused by a bacillus. To make a positive diagnosis of typhoid, a sample of the patient's blood is taken and mixed with typhoid bacilli. If the bacilli agglutinate, the patient has typhoid.

- **a** Why is this a positive diagnosis for the disease?
- **b** Could the person be suffering from some other disease?

28 A person was prescribed an antibiotic for a bacterial infection of the throat. While taking the antibiotic tablets, the patient developed a bacterial infection in their big toe. Explain why the antibiotics that the patient was taking for the sore throat did not prevent the growth of bacteria in the toe.

Extend

29 During the COVID-19 pandemic in 2020, there was debate about the effectiveness of the general public wearing masks. Discuss both sides of this debate.

30 The Russian composer Tchaikovsky died of cholera during an epidemic in Moscow in 1893. It is believed that Tchaikovsky drank unboiled water during the epidemic, some think in a deliberate attempt to commit suicide. Why would drinking unboiled water increase the risk of cholera infection?

31 The body's immune system does not normally react against its own antigens – the body is said to have tolerance for its own antigens. However, sometimes this tolerance breaks down. Conduct research to find out:

- **a** what autoimmune diseases are
- **b** what causes these diseases
- **c** how autoimmune diseases are treated.

32 Investigate and report on the issues surrounding the use of vaccines to protect against human papilloma virus (HPV). Ensure that you provide a balanced discussion of both sides of the subject.

33 Reye's syndrome (pronounced 'rise') is a serious disorder that sometimes occurs in children after a viral infection such as chickenpox or the flu. It was first recognised as a distinct disorder in 1963 by R. Douglas Reye, an Australian pathologist. Reye's syndrome mainly affects children between the ages of 4 and 16 years, and statistics show that it can be triggered by the use of drugs that reduce fever, such as aspirin. Use the Internet to research Reye's syndrome, including its:

- **a** causes
- **b** signs and symptoms
- **c** long-term consequences
- **d** frequency
- **e** prevention.

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